Poster 3.26

ANALYSIS OF RADAR VISIBILITY FOR PROPOSED CANADIAN WEATHER RADARS

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1. INTRODUCTION

Environment and Climate Change Canada is upgrading its weather radar network, Young (2017), and needs to estimate radar visibility in a number of scenarios. In most cases the new S-band radars replace C-band radars on the same site, which involves moving the antenna by only tens of metres in height and the horizontal. At some sites, X-band radars provide temporary coverage after an old C-band radar is removed for the installation of the new S-band radar. For some S-bands entirely new sites must be found. At all sites the primary interest is potential blockages of the radar beam, with a secondary consideration of ground or sea clutter. Information comes primarily statistics of from the existing radar and from calculations using the Shuttle Radar Topology Mission (SRTM) digital elevation models (DEMs) supplemented with other sources. The DEM processing is similar to several previous studies, for example Krajewski et al. (2006), or Kucera et al, (2004), but involves more consideration of tree cover and structures.

2. APPROACH

For pre-existing radar sites the starting point is an historical assessment of blockage of the C-band radars. This helps identify non-terrain issues such as buildings, towers or trees around the site. For obstacles that are within hundreds of metres of the site, azimuth and elevation from the new antenna could differ enough that satellite imagery and local surveys are used to identify them. At long ranges, moving the antenna by tens of metres does not significantly change the angular relationships. These considerations can be used to recommend new tower heights relative to current towers.

For new X- and S-band sites, raw DEM estimates are used for an initial triage of potential sites, followed by more detailed consideration of specific sites. Satellite imagery and site visits flag potential sources of blockage that may be of interest. Since the X-band antennas are only 7m above the ground, a fairly careful assessment of nearby obstacles is needed. On-site measurements can provide height estimates for trees and buildings. Where permitted a drone can take photography from anticipated antenna heights. The DEM analysis software allows the raw terrain data to be supplemented with those estimated heights and the calculations redone. The existence of very local blockage requires the DEM analysis to be done with higher range resolution than most previous studies using the raw DEM.

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2.1 *Statistics*

Since most new S-band radars are replacing existing radars on the same site, data from those existing radars can be used to check for sources of blockage. This cannot predict the magnitude of blockage by the new radars, which will have different beam widths and use different elevation angles. It can flag potential issues that need to be considered. Things that can be immediately clear are terrain blockage, blockage by nearby forest and partial blockage by structures like towers within a few kilometres.

The approach is to start with a long time series of operational reflectivity products in polar coordinates, similarly to Donaldson (2010). Depending on the product, these are at resolutions of 1° x 1km or 0.5° x 0.5km. The data has 256 levels (1 byte) and distributions can be built of the number of times each reflectivity byte value occurs in the time series at each range and azimuth. From the distributions one can find the fraction of the time non-null measurements were reported, or probability of detection above some threshold, or one can convert reflectivity to rain rate using the Marshall Palmer ZR (Marshall, 1948) relationship and calculate the average radar rain rate at each pixel. The objective is to assess blockage and potential sources of blockage and average rain rate will be shown to summarize this. No quality control is attempted and the ZR relationship is always applied, even in cases where snow is the most probable weather target. Average radar rain rate (mm/h) is selected, rather than accumulation (mm), because it does not grow continuously as a time series gets longer. The results are presented in polar coordinates since blockage is a phenomenon along radials and is less well seen on a Cartesian grid.

For summer elevation angles at a typical C-band radar there is a low-level scan at 0.5° elevation, which should be a first order approximation to the 0.4° elevation proposed for the S-Bands. Some existing C-band radars have narrower beams (0.7°) and some C-band have wider beams (1.1°), which changes blockage compared to that from the 0.9° beam of the S-bands. If blockage is confined to the bottom half of the beam, a narrower beam would experience less blockage and a wider beam would experience more. The situation is reversed if blockage extends above the beam's pointing elevation. Winter elevations are lower at typical C-bands and suggest problems that might affect edges of S-band beam.

The main search was for azimuths where data values seem abnormally low compared to the overall precipitation pattern. Narrow sectors of around 1° are usually due to towers nearby, although isolated trees can have a similar effect. Blockage by terrain was only examined if the source seems to be less than 10 km from the radar because at longer distances changes to the tower height make negligible differences to blockage.

One issue with the data is that many C-band radars have old T/R cells and data is being attenuated within as much as 5km from the radar, meaning it can be hard to establish at what range blockage starts.

After examining the radar data. Google Earth is used in an attempt identify sources of blockage within 2km of the radar. Site visits can help identify heights of specific objects such as individual buildings or trees. It can also establish typical tree heights.

2.2 *DEM Based Software*

The blockage estimation program uses a standard radio propagation model (4/3 R_e) and a digital elevation map (DEM) to estimate where radar beams are intercepted by terrain. Here the program is used with data from the shuttle radar topography mission (SRTM) data at resolution of 0.3 arc second resolution, which is about 90m in latitude and about 2/3 of that in longitude, depending on latitude. The program is given the antenna height above ground and for consistency that is added to the DEM topography, as opposed to using the true antenna height above sea level. Where they are known, supplementary objects such as towers, buildings or lines of trees can be added to the underlying terrain database.

The following is an outline of the processing steps:

-Create a polar (range/azimuth) grid of topography by projecting and sampling the SRTM-03 database. For blockage simulation, this is done at high resolution in azimuth and range (0.025° and 0.025km). The extremely high resolution is needed near the radar, where for example a flat surface of 90m extent has a large change in elevation angle as seen from the antenna.

- Add any known objects (lines or points) onto the polar grid. The fine resolution of the grid means these objects can be represented as much smaller than the 90m resolution of SRTM-03.

- Proceed outward along the bins of each azimuth. Convert topography to elevation angle using the standard radar propagation model (4/3 R_e). Also keep track of maximum elevation angle seen before each analysis range bin. This is the minimum unblocked elevation at each range. The possibility of refraction is ignored.

- Given the radar antenna's pointing elevation and vertical beam width, calculate the fraction of the beam intercepted by terrain along this azimuth before the current point. At this point we are in effect assuming an extremely narrow Gaussian "fan" beam oriented vertically.

- Once fractional blockage is calculated at each azimuth, integrate the "fans" across the beam giving each a weight that is related to the horizontal beam pattern. Optionally also consider the fact that the

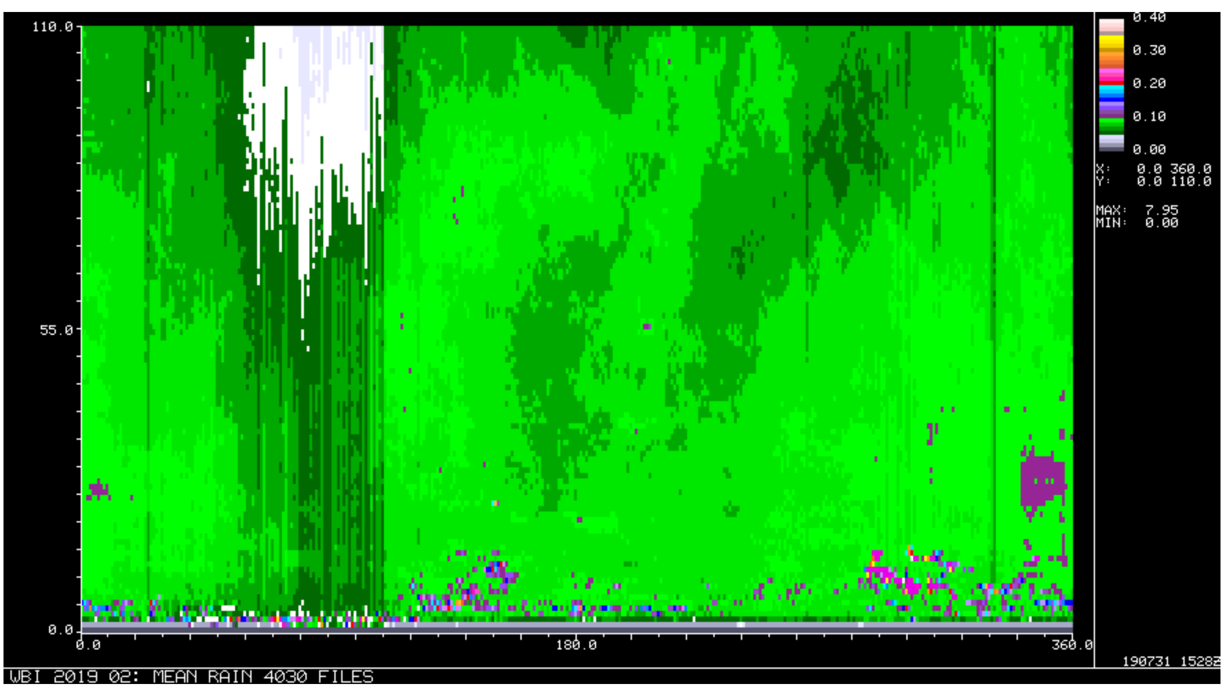

Figure 3.1. Average radar inferred rain rate for CWBI from the PRECIP product, for February 2019 as function of range (y) and azimuth (x). Magenta at lower right is a wind farm. Vertical streaks indicate blockage.

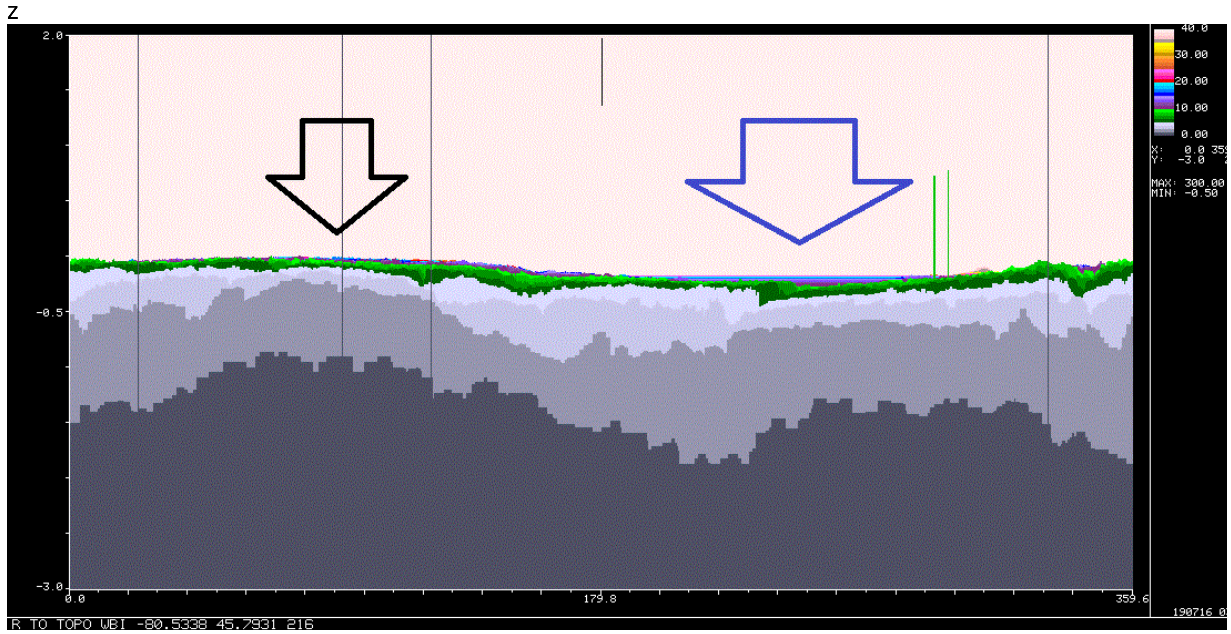

Figure 3.2 Calculated range-to-topography as function of azimuth (x) and elevation (y) for CWBI in the absence of added trees. Black arrow indicates directions where observed blockage starts near the radar. The blue arrow indicates a broad sector where the horizon is flat because is it formed by the surface of Lake Huron. Vertical black lines indicate blockage by communication towers, Green lines represent two of the wind turbines in the Henvey Inlet farm. At top centre an oval (sic) shows the extent of the beam.

antenna rotates during data collection so the effective horizontal beam is larger than the physical antenna beam width.

- One can make a pseudo panorama from the unblocked elevation data using the range to topography calculation: create a (azimuth, elevation) grid and fill it by stepping along each azimuth and noting the minimum range at which a given value of topography elevation occurs (if at all).

Although not shown here, there are a number of other parameters that can be calculated from the polar grid of unblocked elevation. One example is the vertical distance between the ground at a given point and the height of the unblocked elevation angle at the same point. An object of that vertical extent should be visible to the radar. Where this number is high ground clutter can be expected to be rare. One can also calculate compound parameters such as the lowest "safe" elevation at a given range and azimuth: an angle that is at most slightly blocked and reasonably far above any visible terrain, in both elevation and vertical senses of "far".

There are recognized limitations to the approach. The DEM can itself have inaccuracies, for example SRTM03 topography is known to be of lower quality in mountainous terrain, e.g. Makiul et al. (2007) or Kolekca and Kozak, (2014). Buildings and towers are not in the database and realistically only a limited number can be manually added. The real terrain may be covered with trees, which effectively raise the "ground" height, which can only be partially offset by manually adding trees where estimates exist for their heights and locations. The standard radar propagation model does not always apply and there is some concern that the assumed atmospheric profile might not apply on a mountaintop. The approach does not include handling of the antenna's near field, which could matter if blockage is by objects within about 400 m of the new S-band radars.

3. SAMPLE CASE: BRITT RADAR

The existing Britt C-band radar (CWBI) is located on relatively flat terrain above Lake Huron (45.79313 N, -80.53378E). In the absence of any trees or objects, calculations suggest there should be almost no blockage originating near the radar.

Figure 3.1 shows statistical results from the "PRECIPET" product for February. In contrast to the initial blockage calculation there is in fact a broad area of blockage in the east, in azimuths from about 75-100 degrees. Narrow blockage radials at 22°, 93°, 122° and 331° are due to communications towers within 1km of the radar

Streaking in the sector 280-325 degrees, that starts beyond about 7.5km, first appeared in our data only a few months before this analysis and corresponds to the newly constructed Henvey Inlet Wind Farm.

Given that the new radars will have narrower beams and use a higher minimum elevation angle, this and similar statistics from other elevations suggest that the existing antenna height is not too low.

Figure 3.2 shows the result of the DEM calculations in which the database was supplemented by the communication towers and two objects to represent the wind farm. When compared to the statistical results, the fact that the effective horizon in the east (black arrow) is both low and far from the radar indicates a problem with the calculations. A subtler issue is that the calculation shows a broad section of the effective

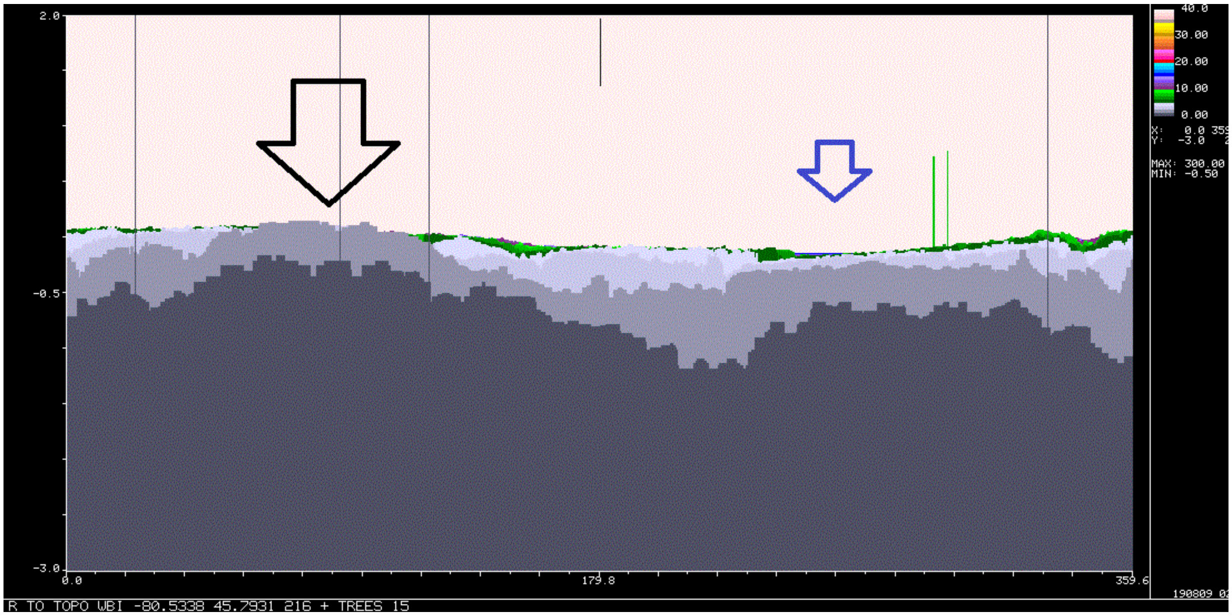

Figure 3.3 Calculated range-to-topography for CWBI with 15m trees added to terrain everywhere. Black arrow indicates directions where observed blockage starts near the radar. The blue arrow indicates narrow sector where the horizon is flat.

horizon is flat, because it is formed by the surface of Lake Huron. When this happens in a (valid) calculation sea clutter will be observed, but that is not the case at this radar,

In fact we know that this area is forested. The DEM blockage calculation was repeated with the assumption that the entire area is covered with trees of height 15m, Figure 3.3. This gave a higher effective horizon in the east. Observed blockage is worse in some angles than this suggests but some individual trees will rise above the typical tree canopy height. If a somewhat more exact calculation were needed an on-site survey could be attempted to estimate representative tree heights.

In the calculations with 15m trees the sector where the horizon appears to be formed by the surface of Lake Huron is greatly decreased, but is still present. This suggests that the real tree cover is a bit higher to shield the lake and prevent sea clutter. This inference may be moderated a bit by the fact that the software has unintelligently placed trees everywhere, including on the lake, so the lake surface is lower than in the calculations.

With respect to sea clutter, the DEM calculations provide a caution about tower heights. If the antenna is raised much above the height of the existing radar then sea clutter problems are possible.

In summary, based on statistics of observed echoes and calculations of horizons based on the SRTM03 DEM, the new antenna height could be slightly higher than the existing antenna but if increased too much there is a risk of sea clutter. These considerations need to be balanced against other issues. For example, the new radar is more powerful than the existing one so the antenna may need to be raised to keep radio exposure levels below safety levels for structures near the radar. Additional action may be needed to refine tree estimates and potentially a drone flown at proposed heights to supplement the calculations.

4. SUMMARY

Ahead of setting tower and antenna heights for new radars a combination of statistics and simulations are being done to identify potential blockage issues. The focus is on blockages within 5 to 10km of the radar since at longer ranges reasonable changes to the tower heights will not significantly change blockage.

These are preliminary input to the tower height selection. Other considerations include RF safety limits at nearby structures and wind loading at mountain top sites.

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