241 ESTIMATING RADAR BEAM BLOCKING RATE WITH SUB-METER DEMS DERIVED FROM PLÉIADES SATELLITES STEREOSCOPIC DATA AND AIRBORNE LIDAR DATA

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1. CONTEXT

Radar beam blocking is an important limitation to the weather radar measurement, and the radar location, the scanning protocol and the data processing have to be optimised in function of this issue. The beam blockages can be due to the relief but also to obstacles of reduced sizes close to the radar.

It is possible to use Digital Elevation Models (DEMs) to simulate the interaction between the radar beam and the ground, and consequently to estimate the beam blocking rate in function of the elevation angle and azimuth of the beam. Following this approach, since 2004 Météo-France has estimated the beam blocking rates due to the relief for all the operational radars of the French weather radar network (37 radars in 2017, for Mainland France and Overseas Territories), by using Digital Terrain Models (DTMs) with spatial resolutions which have evolved from 250m to 25m recently. A complementary human analysis allows to detect and quantify partial beam blockages due to small obstacles close to the radar (mainly within 1km). This identification is based on the analysis of the azimuthal variation of the radar measurement (converted in long-term accumulated rainfall fields), in order to determine sharp and narrow beam blocking which cannot be due to the relief. A verification with aerial photographs or ground photographs generally allows to identify the source (mainly anthropogenic) responsible for the beam blocking (tree, pylon, building, grove …).

This human analysis is time consuming, with a limited accuracy especially if the anthropogenic beam blocking affects large angular sectors, and must be regularly actualised. So, since 2015 Météo-France has been interested by the possibility to simulate directly the impact of the anthropogenic sources of beam blockages, by using very high resolution DEMs regularly refreshed to describe the immediate environment of the radar. This paper presents two different examples of such simulation, and discusses the results for each case study.

2. METHODOLOGY

The simulation process of the beam blocking rates uses different DEMs in function of the distance to the radar, two DTMs provided by IGNEspace representing the elevation of the bare ground of the terrain with a spatial resolution of 75m and 25m (*i.e.* the relief), as well as a sub-meter resolution Digital Surface Model (DSM) which includes the elevation of all vegetation and structures on the ground:

- the sub-meter DSM is used for ranges within few km from the radar.
- the 25m DTM is used for ranges from the radar between few km and 50 km,
- the 75m DTM is used for ranges beyond 50 km from the radar (up to 256 km).

The simulation software, named Surfillum-Vishydro, has been developed by the LTHE laboratory (now IGE), and presents the interest to integrate the interaction between the radar beam and the ground with a great (and adaptable) angular and radial resolution, taking into account an antenna diagram as a model of angular distribution of the energy into the main beam (Delrieu et al., 1995). This software also allows to estimate ground clutter values, and to combine the estimated blocking rate with a VPR model in order to estimate the "hydrologic visibility" of a radar as defined by Pellarin et al., 2002 (not used in this work). It has been used several time for operational studies (Faure et al., 2005; Faure, 2006), and by Météo-France since 2004 for its operational needs. A small evolution in 2016 has allowed to use simultaneously several different DEMs.

The simulation results obtained with the three DEMs described above, have been compared to those of the current operational procedure: simulation with only the two DTMs completed by the human analysis. Two types of DSM have been used: issued from Pléiades satellites stereoscopic data and from airborne Lidar data.

3. UTILISATION OF A 0.5 - METER DSM DERIVED FROM PLÉIADES SATELLITES STEREOSCOPIC DATA

3.1 Analysis of this case study

This first application of a sub-meter DSM concerns an operational C-band radar operated by Météo-France and located in the great urban area of Bordeaux. This urban context, in a relatively flat area, implies a great number of buildings, pylons, and trees within few km from the radar, but also three important structures: the control tower and some airplane hangars of the airport, and a water tower (picture 1). The used DSM (figure 2) has a large size: 19.5x18km² representing more than 1.4 billions pixels of 0.5x0.5m². It was generated for this

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study by IGNEspace from Pléiades satellites stereoscopic images (orbiting at 694 km of altitude). Pléiades images are an example of the current Earth observation from space capabilities, with a very-high spatial resolution and an interesting standard temporal resolution of few days, with the possibility to schedule daily image acquisitions on a specific site.

Figure 3 shows the simulated beam blocking rates with and without the information provided by the sub-meter DSM, for a 0.4° elevation angle of the radar beam. One can see a general estimated blocking rate increase with the DSM, due to the anthropogenic urban background, excepted in a east sector where the results are the same, corresponding to a partial beam blocking due to distant relief. In few narrow sectors the beam blocking rate dramatically increases with the DSM, due to the shielding of the three above-listed structures and of a tree in the south-west direction.

If the information provided by the sub-meter DSM allows to better take into account the overall urban background impact on the radar's visibility, the azimuth by azimuth comparison with the human analysis results (figure 4) shows that the DSM accuracy is not sufficient to completely represent the effect on the radar measurement of each isolated and elevated structure or tree.

3.2 Discussion

In this case study, the used sub-meter DSM seems to allow to simulate the cumulated effect at the horizon of the heterogeneous background environment of the radar in a relatively flat area, but not to accurately simulate the partial beam blocking generated by all the isolated structures or trees.

One can note that the DSM accuracy depends on the satellite stereoscopic data quality, but also on the data processing performance. For example, the first treatment used to generate this DSM filtered all the elevated towers: the control tower, the water tower, and the radar tower (red arrows in figure 2). A second treatment of the same Pléiades images with more adapted parameters detected these towers, without modification of the rest of the DSM values. So, the estimation of a DSM with these stereoscopic data requires minimal expertise, and it might be possible to obtain better results than the ones presented with an optimised data processing.

Figure 1: Aerial view around the radar, and structures seen from the radar.

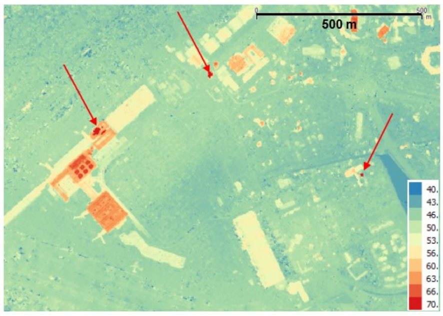

Figure 2: DSM sample around the radar location (altitudes in meters).

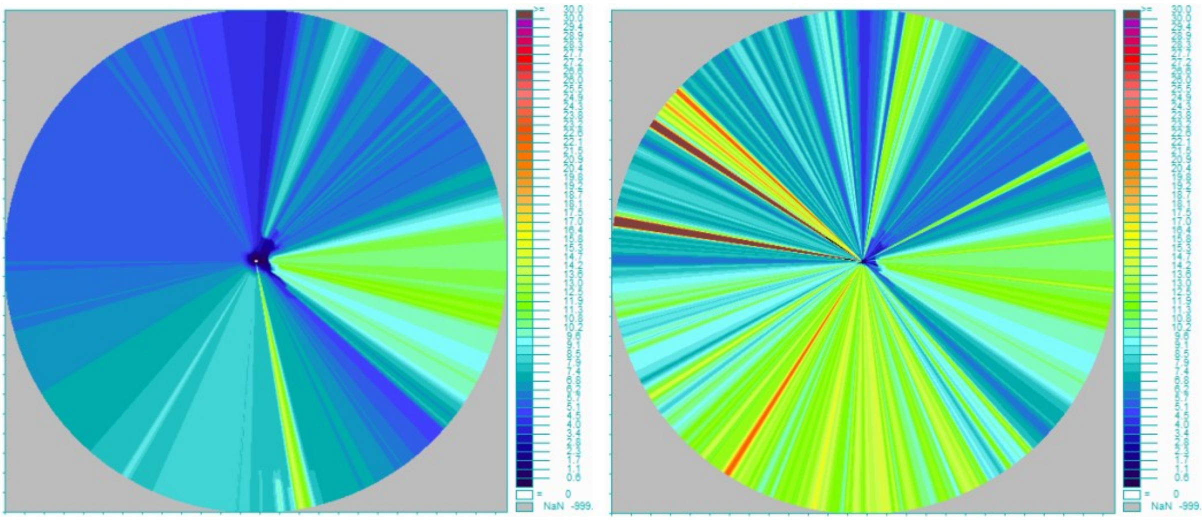

Figure 3: Simulation of the beam blocking rate of the Bordeaux's radar for the 0.4° elevation angle (scale = 0% to 30% of beam power). Left = without DSM data. Right = with DSM data. Radius = 256 km around the radar.

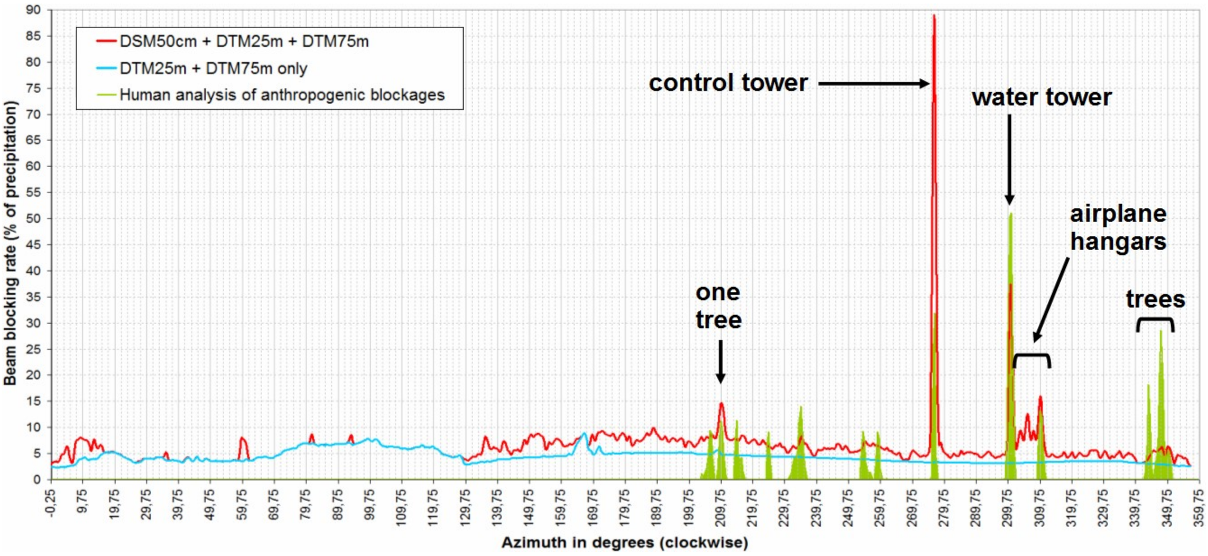

Figure 4: Simulation of the partial beam blocking rate (0% to 90% of precipitation values) in function of the azimuth: comparison of the results with (red) and without (blue) the DSM data, and of the narrow blocking rates identified by human analysis (green). The simulated beam blockage for the control tower is very over-estimated at the 0.4° elevation angle because of the tower geometry, but is much accurate for the 1.5° elevation angle.

4. UTILISATION OF A 1- METER DSM DERIVED FROM AIRBORNE LIDAR DATA

4.1 Analysis of this case study

This second application concerns an operational C-band radar (named Falaise) operated by Météo-France in a rural setting, and close to some woods. The used DSM has a limited size around the radar: 2.4x2.1km² representing 5 millions pixels of 1x1m². It was generated by a specialised provider, from measurements of a ALS70 Lidar system on a P68-TC aircraft (figure 5). The mean point density of measurements from 1550m AGL is 11pt/m², reduced to a Cartesian DSM of 1-meter resolution. This set of airborne Lidar data is an example of local Earth observation from a small aircraft at low altitude and reduced cost.

Figure 6 shows the impact of each structure or tree on the digital elevation model, and the resulting simulated beam blocking rates for a 0.4° elevation angle of the radar beam. The small circles indicate the top of the trees higher than the axis of the beam altitude, corresponding to more than 50% of blocking rate. As the radar is on a small hill, and the region relatively flat, the blocking rate due to the relief is limited. So, the picture 7 shows the simulated beam blocking rates with the 1m-resolution DSM, for a 0.4° elevation angle, and the result without this DSM but with the human analysis completed in 2014. The two maps are very similar, and the DSM seems to improve the beam blockages estimation.

Figure 5: The flight plan over the radar area.

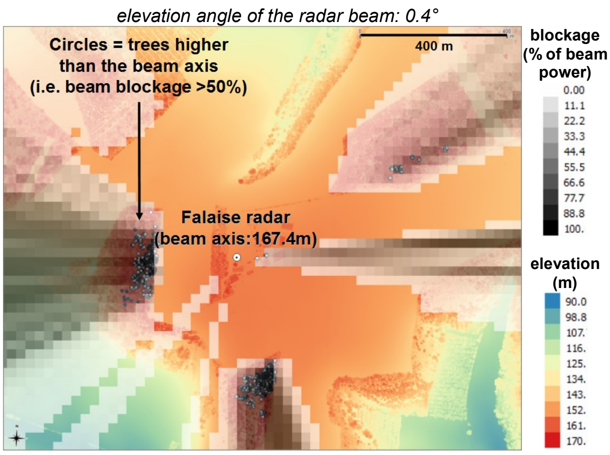

Figure 6: DSM sample around the radar location (altitude in meters) and simulated beam blocking rates (reduced to a Cartesian grid of 24m resolution).

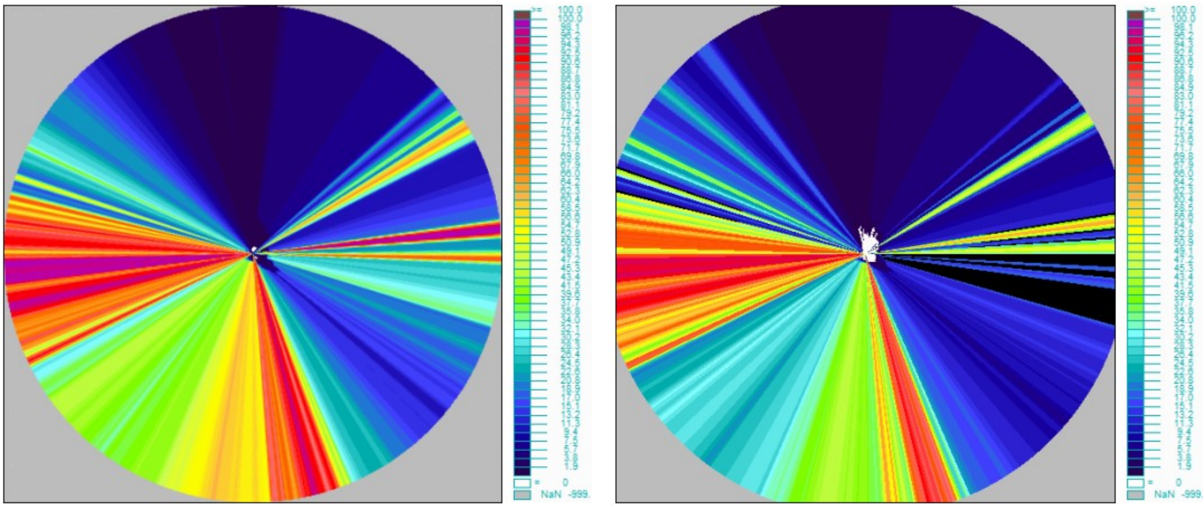

Figure 7: Simulation of the beam blocking rate of the Falaise radar for the 0.4° elevation angle (scale = 0% to 100% of beam power). Left = with DSM data. Right = without DSM data but with human analysis. Radius = 256 km.

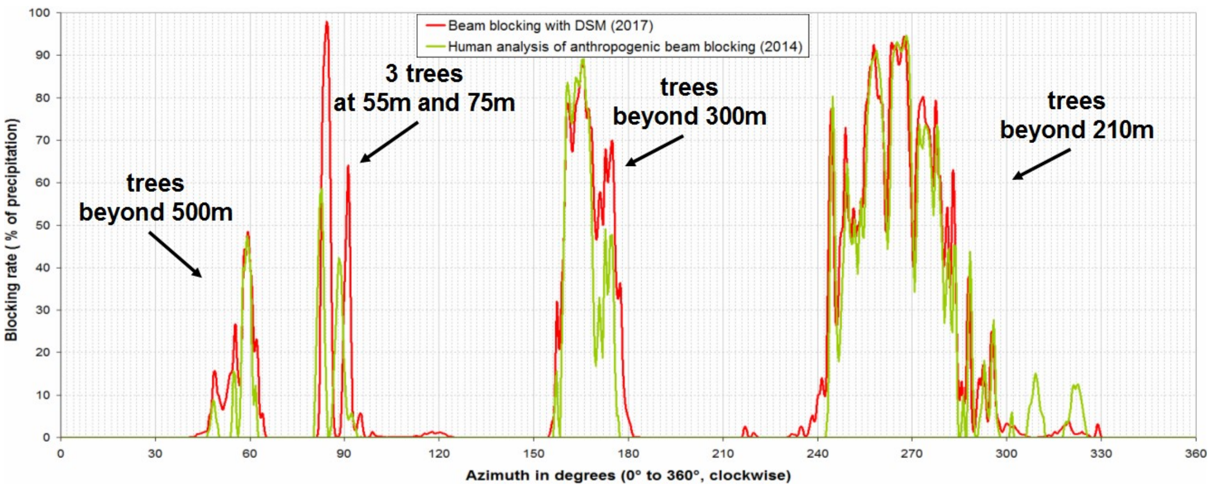

Figure 8: Simulation of the beam blocking rate (0% to 100% of precipitation values) in function of the azimuth, for the 0.4° elevation angle: In red, the result with the 1-meter resolution DSM only; in green, the blocking rate identified by human analysis.

The figure 8 shows the azimuth by azimuth comparison of the simulation using only the 1-meter resolution DSM, with the result of the human analysis realised three years before. Excepted for three isolated trees at only 55m and 75m from the radar (which could have grown), the two results are exceptionally consistent.

4.2 Discussion

In this case study, the used 1-meter DSM allows to simulate with accuracy the impact of the woods close to the radar and, may be, could authorise simulation of individual trees. The airborne Lidar data specifically acquired around a radar location have a cost (limited), but the accuracy of the measurement is assumed to be of a few centimeters in location and height, and such data could be very interesting to use when it's possible or necessary. In the presented work, the Lidar DSM was already estimated for an other study, and the beam blocking rate simulation was an opportunistic utilisation.

5. CONCLUSION

The radar beam blocking is frequently an important limitation to the weather radar measurement, and is not easy to characterise when the sources are not the relief. It's an issue for the existing operational radars, but also for the selection of the best site where to build a future radar.

This work shows two examples of use of sub-meter resolution Digital Surface Models, to simulate the impact of the anthropogenic environment of a radar on the radar visibility. These simulations was expected to significantly improve the estimation of the actual beam blocking rates, particularly in case of important anthropogenic impact, *i.e.* high partial beam blocking rates and large angular sectors affected. Two types of DSM have been used, estimated from data of two common Earth observation systems.

The satellite data, as the stereoscopic images of the Pléiades satellites, have the interest to be available, but sub-meter DSMs issued from these data are not still a common product on the all territories. So it might be necessary to realise a specific DSM estimation on a radar location before to use it. The results presented section 3 show that this kind of sub-meter DSM, at least, can allow to simulate the radially cumulated radar beam blocking due to the close anthropogenic environment of a radar. Other case studies would allow to better estimate the capacity of simulating, with these satellite data, the radar beam blockage induced by individual obstacles, or the impact of little groves like around the Falaise radar.

The DSMs derived from airborne data present the interest to be estimated with data specifically acquired over the area of interest, from a low or very low altitude above the ground. These airborne data could already be available, particularly in urban areas, but it is important to use updated data (Cremonini et al., 2016). In the future, aerial data could be acquired with unmanned aerial vehicles, and automated software could facilitate the DSM estimation (McCabe et al., 2017), which could even more reduce the cost and facilitate the use of this kind of DSM. The results presented section 4 show that these meter or sub-meter DSMs can allow to simulate very accurately the radar beam blocking rates due to the anthropogenic environment of a radar, even in rural setting. One can note that radar beam blocking rates for groves are less affected by the growth of the trees or by seasonal variations, than for isolated trees. These new results can be compared to other recent results in Cremonini et al., 2016, using airbone laser scanning data (mean resolution 0.5pt/m²) to estimate radar beam blocking rates in the Helsinki metropolitan area, Finland.

Finally, one can remark that for a particular structure like a control tower, whatever the data source, a DEM can't take into account an inverse vertical variation of the structure width, inducing an increase of the beam blocking rate when the elevation angle of the beam increase. In this case, an accurate simulation needs to precisely project a model of the structure into the radar beam, as used for electricity pylons in Faure 2006.

5. ACKNOWLEDGEMENT

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