Design of a clutter modelling algorithm based on SRTM DEM Data and adaptive signal processing methods.

E. GONZALEZ-RAMIREZ[1] & M. A. RICO-RAMIREZ[2] & I. CLUCKIE[3] & J. I. DE LA ROSA VARGAS[1] & D. ALANIZ-LUMBRERAS[1]

1 *Autonomous University of Zacatecas, Zacatecas, Mexico*
gonzalez_efren@hotmail.com

2 *University of Bristol, Bristol, United Kingdom*

3 *Swansea University, Swansea, United Kingdom*

Abstract This paper presents a robust algorithm for clutter modelling based on the radar equation, radar characteristics and digital elevation data. Optimization methods from adaptive signal processing theory were used to calculate the weights of an adaptive linear combiner representing the radar system for clutter modelling. Modelled clutter showed an acceptable precision demanded by applications on meteorology and hydrology for radar rainfall estimations.

Key words weather radar; modelling; SRTM; adaptive linear combiner

1. INTRODUCTION

Weather radar is an important system for qualitatively and quantitatively rainfall estimation. The radar antenna is oriented to scan the ground at low elevation angles allowing to have the best estimation of rainfall reaching the ground. This technique has an inconvenient since at these grazing angles of the antenna the radar beam hits the ground as well as meteorological targets.

The signal arriving at the radar antenna contains rainfall information embedded with ground echoes. These echoes are known as ground clutter and they have to be filtered to minimize their effects on rainfall estimates. Several techniques are currently used to remove clutter. For instance, clutter map is a technique consisting on measuring echoes intensity when rainfall is not present. These echoes are usually flagged and removed when the radar system is used for rainfall estimation. This technique is effective in removing most of clutter under standard atmospheric conditions (Harrison *et al.*, 2000). Other techniques that employ radar data from single- and dual-polarisation weather radar are used for automatic classification and removal of ground echoes as well as anomalous propagation (AP) as described in Cho *et al*. (2006); Berenguer *et al*. (2006); Gourley *et al*. (2007); Rico-Ramirez and Cluckie (2008). The presence of ground clutter not only has detrimental effect on rainfall estimation but they are also used to sense the performance of the weather radar system such as the calibration of weather radars at attenuating wavelength (Serrar *et al*., 2000) and to control radar signal stability (Sempere-Torres *et al*., 2001, 2003). When filtering a signal is of great importance to know its characteristics in order to recover it when such a signal is mixed with other signals and noise. High resolution Digital Terrain Model (DTM) data allow the modelling of clutter in a simple manner. Examples of such clutter models are described in Delrieu *et al*., (1995); Andrieu *et al*., (1997); Archibald, (2000); and Gonzalez-Ramirez, (2005).

2. DATA

The radar data used to validate the results were obtained from the Thurnham radar located in the South East of England (latitude 51.2942°, longitude 0.6059° and altitude 219 m above mean sea level). The radar system is a multi-parameter C-band radar with simultaneous transmission and reception of horizontal and vertical polarized waves. This radar system has the power divider and receiver in the pedestal to maximise data quality. The nominal beam width of the radar is 0.95 degrees, with an antenna diameter of 4.2m and with typical gate resolutions of 125 m, 250 m and 500 m. The transmitting peak power is 250 kW. Every PPI scan has one ray per degree.

The DTM data were obtained from the Shuttle Radar Topography Mission (SRTM), which are available for the entire world with a resolution of 3 arc second (approximately 90m resolution at the Equator). There are also data available with 1 arc second resolution, but this data set is not available for all countries. Farr *et al.* (2007) describes in detail the instrumentation and data processing to generate the SRTM DTM data. For the purpose of this research, 3 arc second resolution SRTM DTM data were employed. The SRTM DTM data are available for download as 5x5-degree tiles in the geographic coordinate system WGS84. The SRTM DTM data were processed and mapped to horizontal 50m x 50m squares in the United Kingdom National Grid (UKNG) system to be employed by the clutter predictor software. The transformation of SRTM geographic grid to UKNG was carried out by transforming the geographic coordinates of SRTM data cell vertexes based on the WGS84 datum to geographic coordinates based on the Airy datum, converting these geographic coordinates to UKNG eastings and northings coordinates and approximating the SRTM curved grid to a grid with four non-parallel linear sides. Elevation values for each 50m x 50m square were computed as a weighted average of the elevation value of the overlapping 3 arc x 3 arc SRTM grids. The weight for each overlapping 3 arc x 3 arc SRTM grid used in the average was taken as the ratio between its overlapped area and the total area of the 50m x 50m square.

3. MODELLING OF GROUND CLUTTER ECHOES

The averaged reflected power from meteorological echoes is given by (Battan, 1973; Skolnik, 1980):

$$\overline{P}_r = \frac{C_0 |K|^2 Z}{r^2} \qquad (1)$$

where C_0 is a constant that depends on the characteristics of the radar system (see Battan, 1973), $|K|^2$ is the dielectric constant of the scattering particles (assumed to be equal to 1), Z is the radar reflectivity factor and r is the range from the radar to the meteorological echoes (i.e. the target). In a similar way, Equation (1) can also be employed to compute the reflectivity measured by the radar from ground clutter echoes if P_r is known.

The received backscattered power at the radar antenna from a 50m-square-shaped portion of the ground r metres away from the radar site can be calculated by the use of the radar equation for any kind of target (this includes hydrometers and portions of the ground) as given in Battan, (1973):

$$P_r = \left(P_T G^2 \lambda^2 \sigma_t\right) / \left(4^3 \pi^3 r^4\right) \qquad (2)$$

where the parameters P_T , and λ are constant; σ_t is based on the land type according to the results shown by Billingsley (2002) and demonstrated in Gonzalez-Ramirez (2005). The value of G depends on the angular position of the target with respect to the radar main beam axis according to the shape of the electric field. Finally, the backscattered power from all targets within the resolution volume can be computed by using Equation 3 (see also Delrieu *et al*., 1995) considering a symmetric beam shape with respect to the main beam axis (i.e. depending only on r and θ) and assuming no attenuation by atmospheric gases, that is:

$$\overline{P}_r = \frac{P_T \lambda^2}{(4\pi)^3} \iint_S \frac{G^2(r,\theta,\phi)\sigma_t(r,\theta,\phi) I_t(r,\theta,\phi)}{r^4} dS \qquad (3)$$

The quantity I_t takes the value of one when the target is illuminated and zero otherwise. Clutter reflectivity from a beam volume unit can be formulated as an adaptive linear combiner in which the received power is equal to the summation of all received powers from ground targets within the beam volume and using Equation 1 to transform it to reflectivity. The energy from ground targets can be grouped according to their angle from the radar main axis θ. The total received power from a ground target located at range r_i away from the radar antenna can be approximated as:

$$k_{i1} f(\theta_1) + k_{i2} f(\theta_2) + \cdots + k_{iN} f(\theta_N) = Z_{r_i} \qquad (4)$$

where the values k_{ij} ($j = 1,2,\cdots,N$) are computed based on DTM data, radar parameters and considering results from Billingsley (2002) for the computation of σ_t of ground targets. $f(\theta_j)$ is a function which depends on the angle θ_j of the ground targets and measured from the main beam axis, and Z_r is the reflectivity measured by the radar.
For a ray, the system equation becomes:

$$\begin{gathered} k_{11} f(\theta_1) + k_{12} f(\theta_2) + \cdots + k_{1N} f(\theta_N) = Z_{r_1} \\ \vdots \\ k_{M1} f(\theta_1) + k_{M2} f(\theta_2) + \cdots + k_{MN} f(\theta_N) = Z_{r_M} \end{gathered} \qquad (5)$$

This system equation can be solved by the adaptive Least Mean Square (LMS) algorithm described by Widrow (1985).

4. RESULTS

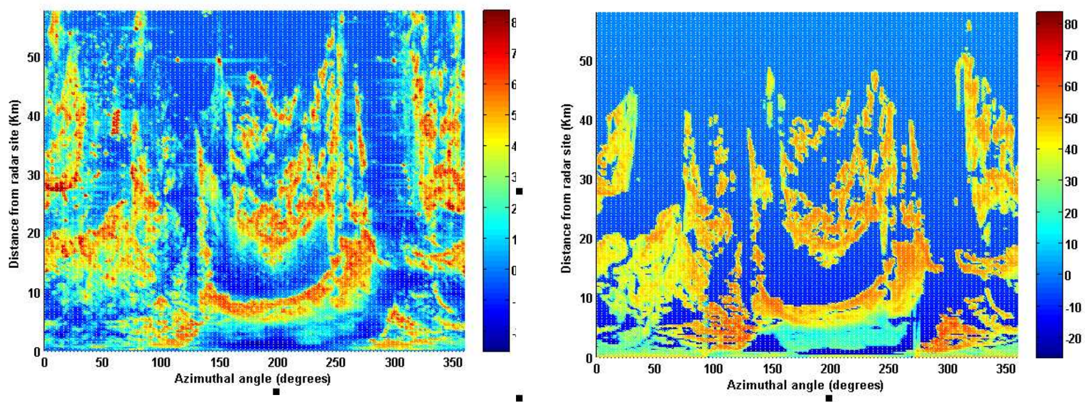
Most of the clutter at 0.0 degrees of elevation are concentrated in the first 50km and show low distortion due to the moving image effect found in higher elevation angles. Therefore, data from the lowest elevation angle were used to validate modelled clutter (i.e. 0.0 degrees). The clutter reflectivity data were available in a 230x360 matrix where the rows represent the gates with a resolution of 250m and the columns represent the rays with one-degree resolution. Data were filtered row by row using the Wiener filter to minimize detected noise assumed to be a time invariant additive Gaussian white noise with 0.9355 of standard deviation.

The ground clutter was modelled using the functions $f(\theta_j)$ found in the LMS algorithm and were compared with measured data from the Thurnham radar prior conversion to reflectivity. Measured and modelled clutters are shown in Figure 1a and 1b respectively. The correlation between measured and modelled ground clutter echoes was 0.74. 51.4% of clutter present in the measurements was also shown by the clutter modelling algorithm. From the total number of clutter pixels detected by the Thurnham radar, 48.3% were located on the sea, where the clutter algorithm shows no significant echoes. In this region, measured reflectivity data showed some geometric textures probably formed by echoes from chips and man-made structures on the coast and in the sea which were not included in the DTM data set. Other type of clutter is also shown with low intensity echoes. This can be observed in Figure 1a located approximately 49.5km from the radar location at 149 degrees in azimuth. A trace formed to the right and left of this set of clutter was probably caused by the radar system receptor rather than by the ground. Small distortion is also observed being more evident in the azimuth range from 300 to 360 degrees. This distortion is produced by the radar system and is more noticeable as the elevation angle increases.

There were 0.3% of clutter echoes present at places marked as obscured ground in the modelling algorithm representing in overall a small percentage. Discrete objects (those high objects with high capacity of reflection but very narrow so are unnoticeable in the DTM data set) may cause these type of clutter since they are visible from the radar antenna.

Figure 2 shows the distribution of the differences between modelled and measured clutters. The measured intensity of the clutter echoes from the Thurnham radar were subtracted from the modelled clutter using the algorithm proposed in this paper. The results show that differences have a mean of 1.77 dB and a standard deviation of 16.12 dB. The skew observed in this histogram is probably due to the effect of contamination of noise created in the receptor of the radar system (some kind of saturation or energy holding may exist in the elements of the receptor).

Figure 4 shows the correlation between modelled and measured clutters. The minimum correlation between these two sets is present at 23 degrees with 0.295 and the maximum correlation is at 257 degrees with a correlation of 0.886. The average correlation was 0.714. The worst performance of clutter modelling was found between the azimuth angles of 9 and 43 degrees. This region is mainly covered by the sea and this explains the poor correlation. Also, it is likely that shipping and man-made structures in this region are also affecting the results.



a) b)

Fig. 1 a) Measured clutter from the Thurnham radar for a complete scanning, b) Modelled clutter from the Thurnham radar for a complete scanning.

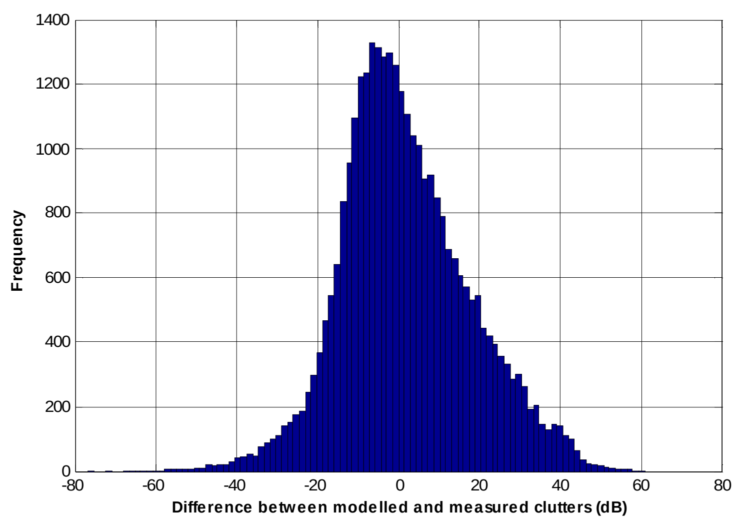


Fig. 2. Histogram of differences between clutter from modelling and measurements.

5. CONCLUSIONS

A robust ground clutter algorithm based on DTM data, the radar equation and results from Billingsley (2002) has been developed. The algorithm allows the computation of the position and approximate intensity of most of clutter present in any weather radar. The main advantage of calculating ground clutter echoes from DTM data is its applicability of reducing the effect of this unwanted signal over echoes with hydrological and meteorological interest. Other important advantage is the availability of DTM data from the Shuttle Radar Topography Mission (SRTM), which are freely available on the web.

There were measured ground clutter echoes not shown by the ground clutter model. These echoes are mainly from discrete objects on the land such as towers, buildings, etc., and on the sea such as chips and man-made structures which are not included in the DTM data.

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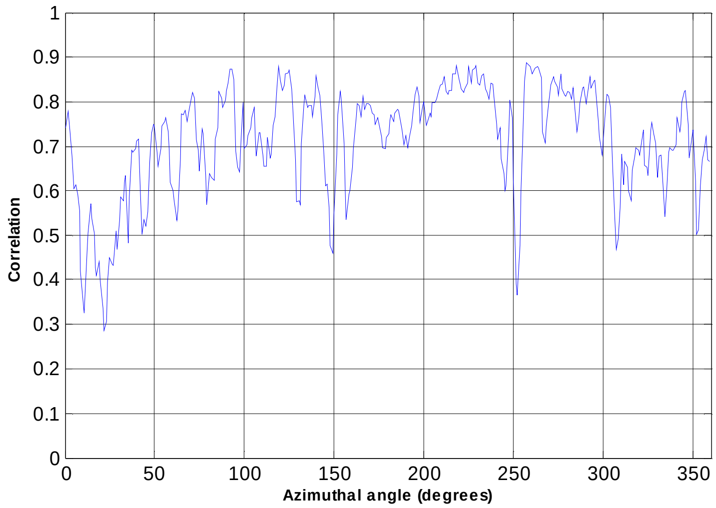

Fig. 3. Azimuth angle of radar rays versus correlation between modelled and measured clutter.

REFERENCES

Andrieu H, Creutin JD, Delrieu G & Faure D. (1997) Use of weather radar for the hydrology of a mountainous area. Part I: radar measurement interpretation. *Journal of Hydrology* **193**, 1-125.

Archibald E. (2000) Enhanced Clutter Processing for the U.K. Weather Radar Network. *Physics and Chemistry of the Earth, Part B: Hydrology* **25,** 823–828.

Battan, LJ. (1973) Radar observation of the atmosphere. The University of Chicago Press.

Berenguer M, Sempere-Torres D, Corral C and Sanchez-Diezma R. (2006) A fuzzy logic technique for identifying nonprecipitating echoes in radar scans. *Journal of Atmospheric and Oceanic Technology* **23**: 1157–1180.

Billingsley JB. (2002) Low-angle radar land clutter: measurements and empirical models. William Andrew Publishing.

Cho Y, Lee G, Kim K & Zawadzki I. (2006) Identification and removal of ground echoes and anomalous propagation using the characteristics of radar echoes. *Journal of Atmospheric and Oceanic Technology* **23**: 1206–1222.

Delrieu G, Creutin JD & Andrieu H. (1995) Simulation of radar mountain returns using a digitized terrain model. *Journal of Atmospheric and Oceanic Technology* **12**: 1038–1049.

Far TG, Rosen PA, Caro E, Crippen R, Duren R, Hensley S, Kobrick M, Paller M, Rodriguez E, Roth L, Seal D, Shaffer S, Shimada J, Umland J, Werner M, Oskin M, Burbank D & Alsdorf D. (2007) The Shuttle Radar Topography Mission. *Reviews of Geophysics* **45**, RG2004, 1-33.

Gonzalez-Ramirez E. (2005) Weather Radar Data Analysis Oriented to Improve the Quality of Rainfall Estimation. Ph.D. thesis, University of Bristol, UK.

Gourley JJ, Tabary P & du Chatelet JP. (2007) A fuzzy logic algorithm for the separation of precipitation from non-precipitation echoes using polarimetric radar observations. *Journal of Atmospheric and Oceanic Technology* **24**: 1439–1451.

Harrison DL, Driscoll SJ and Kitchen M. (2000) Improving precipitation estimates from weather radar using quality control and correction techniques. *Meteorological Applications* **7**: 135–144.

Rico-Ramirez MA & Cluckie ID. (2008) Classification of ground clutter and anomalous propagation using dual-polarization weather radar. *IEEE Transactions on Geoscience and Remote Sensing*, **46**(7), doi:10.1109/TGRS.2008.916979.

Sempere-Torres D, Sanchez-Diezma R, Berenguer M, Pascual R, & Zawadzki I. (2003) Improving radar rainfall measurement stability using mountain returns in real time. In 31th Int. Conference on Radar Meteorology, Seattle, WA, AMS.

Sempere-Torres D, Sanchez-Diezma R & Cordoba MA, Pascual R, and Zawadzki I. (2001) An operational methodology to control radar measurements stability from mountain returns. In 30th Int. Conf. on Radar Meteorology, Munich, Germany, AMS.

Serrar S, Delrieu G, Creutin JD & Uijlenhoet R. (2000) Mountain reference technique: Use of mountain returns to calibrate weather radars operating at attenuating wavelengths. *Journal of Geophysical Research* **15**: 2281–2290.

Skolnik M. (1980) Introduction to Radar Systems. McGraw-Hill.

Widrow B. & S. D. Stearns (1985) Adaptive Signal Processing. Prentice-Hall, Inc.