Evaluation of topside equatorial spread F spectra estimators using Monte Carlo simulations

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Introduction

Radar observations typically employ periodic pulses to study any target. This scheme allows a simple processing of the data but the results frequently shows range or frequency aliasing. In order to solve this problem Uppala and Sahr [1] introduced the aperiodic technique (AT) in the radio science community. The AT is based on transmitting pulses at non uniform intervals and allows to study moderately overspread targets. Some equatorial Spread F (ESF) echoes belong to this category, particularly those from the topside. Using this idea Jicamarca Radio Observatory (JRO) has done a couple of experiments to study ESF echoes. Chau et al [2] used the Fast Fourier Transform (FFT) to compute spectra from those experiments and developed some criteria to remove clutter due to the aperiodic sequence. A second scheme of work was introduced by Hysell et al [3] and this scheme uses a Bayesian method to compute the spectra. Continuing this line of research a Monte Carlo simulations of typical echoes from equatorial ionospheric irregularities as well as ground clutter has been done to evaluate different aperiodic pulsing and inversion techniques to estimate the spectra or its corresponding Auto-Correlation Function (ACF).

Our main objective is the estimation of the moderately overspread topside equatorial spread F (ESF) spectra. The optimal spectra estimators combined with radar imaging techniques might represent the unique means to estimate the irregularity power and energy spectral density versus wavenumber from the ground.

Aperiodic Pulsing Schemes

Based in the works of Uppala and Sahr [1] and Uppala and Sahr [4] we have evaluated two schemes which are called arithmetic progression (AP) codes and arithmetic modulus (AM) codes. Both codes show slight deviation from periodic schemes. The fundamental idea of the aperiodic technique is shown in the Figure 1 and the equations 1 and 2 define those codes:

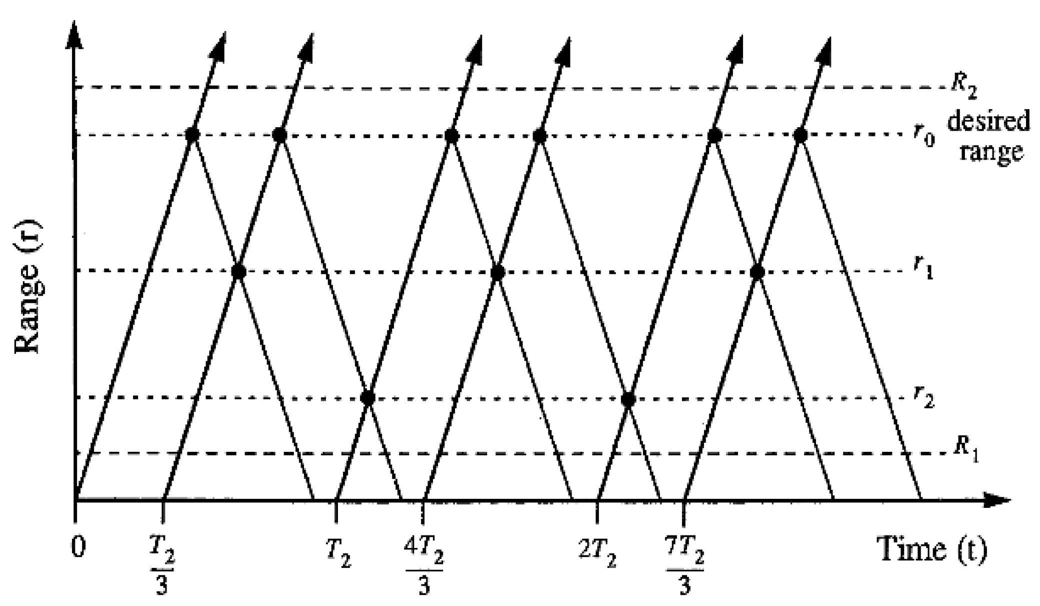


Figure 1: The Figure illustrates the criteria used in the aperiodic pulsing. The horizontal axis shows the transmission times where T_2 is the period of the transmitted sequence. This type of scheme allows to detect the clutter once per cycle of transmission. (The Picture was extracted from Uppala and Sahr, 1994)

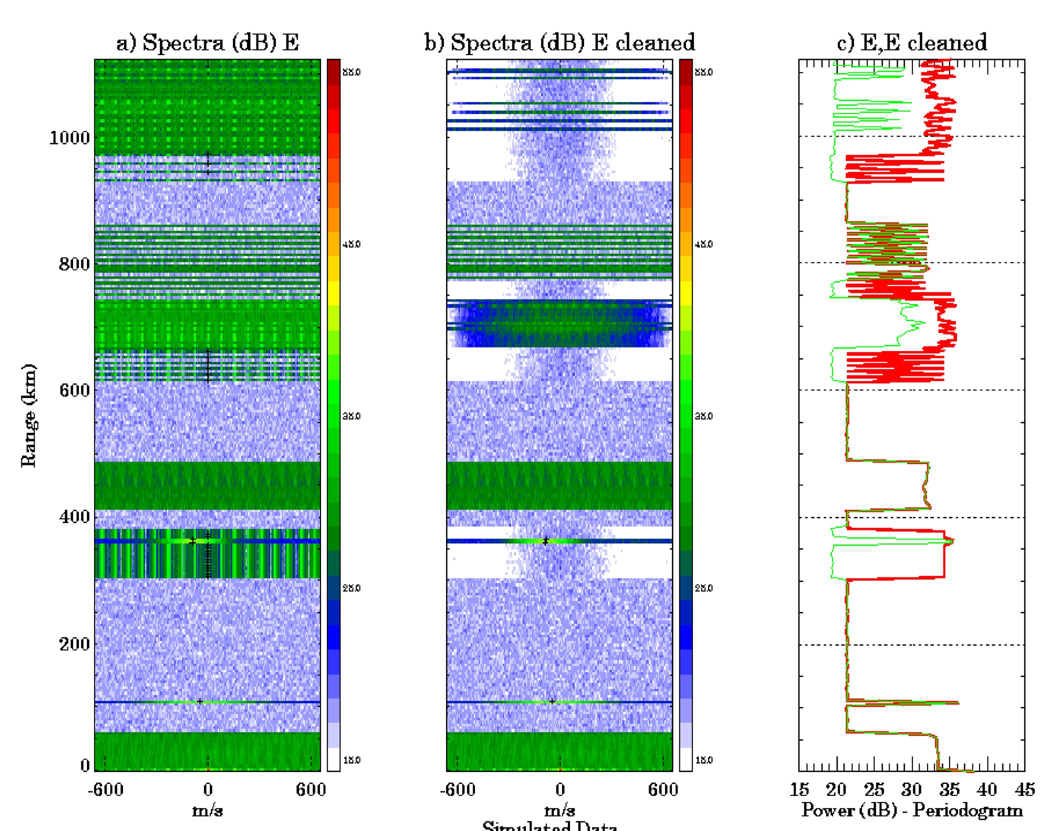
$$AP:(s_{i+1}-s_i)=[a, a+d, a+2d, \ldots, (N-2)d]; i=1,2,\ldots,(N-1) \ldots (EQ1)$$

$$AM:(s_{i+1}-s_i)=[a, a+(k \bmod p)d, a+(2k \bmod p)d, \ldots, ((N-1)K \bmod p)d] \ldots (EQ2)$$

In both equations “a”, “d” and “N” represent the minimum difference from one transmitted pulse to the next, the increment of the difference in the transmitted pulses and the number pulses per cycle respectively. For the EQ 2, “k” is a variable to arrange the order of the progression and “p” represents a number primer relationship with the number of pulses N in the code. In both cases the average pulse spacing is T_N/N.

Figure 2 shows echoes from clutter (~0km), equatorial electrojet (EEJ) (~100km) and ESF (~360km). In addition the behaviour due to the aperiodic scheme can be observed.

Figure 2: The Figure shows the spectra generated by the clutter, EEJ and ESF echoes due to the aperiodic sequence of pulses (Arithmetic progression). The contribution of these echoes into the spectra depends of the correlation time (a=301.5km, d=4.5km and N=17)



Inversion Techniques

Four different techniques have been used to estimated the spectra: Periodogram (PE), Lagrange Interpolation (LI), Maximum Entropy (ME) and Gaussian Fitting (GF). The PE uses the FFT to compute the spectra (details in [1]). LI transform the aperiodic sequence to periodic interpolating samples every T_N/N. ME is described by Hysell and Chau [5] and uses the Shannon Entropy of the target spectrum as a prior probability. The last technique is the GF where the real and imaginary part of the ACF are simultaneously fitted. The Figure 3 compare typical spectra obtained using these techniques. The model is plotted in black and other colours represent the different techniques used to the spectra.

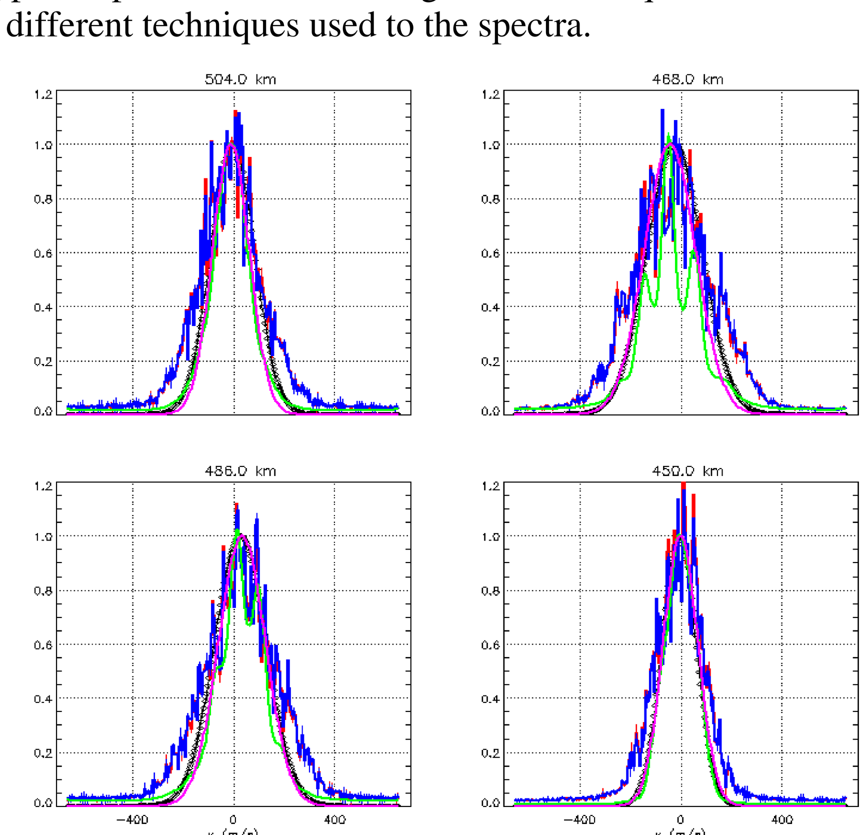


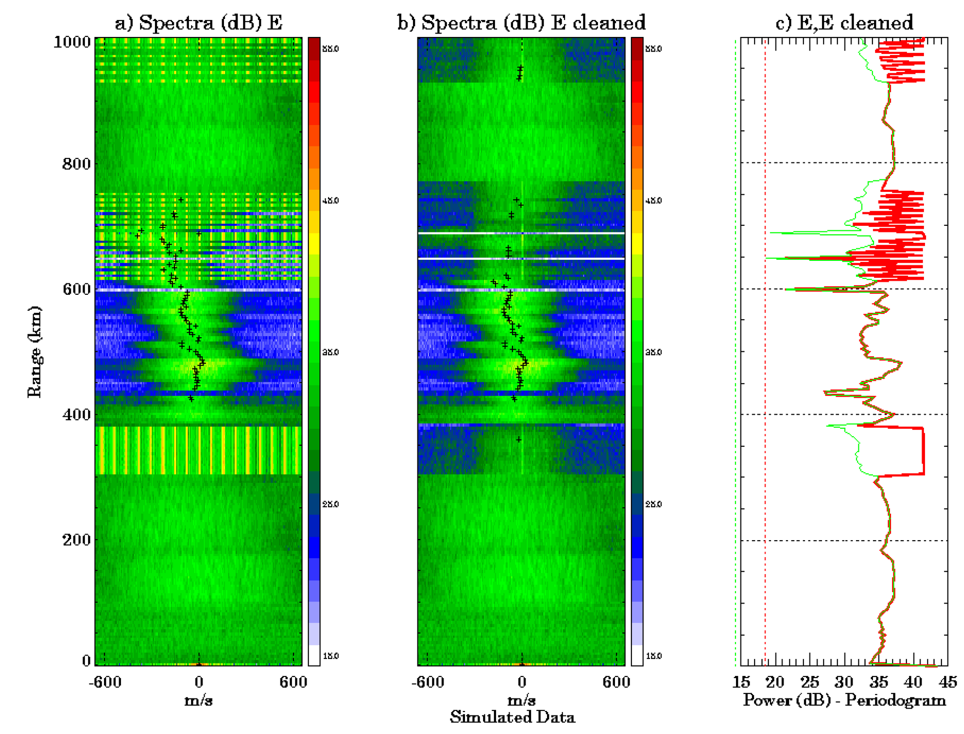
Figure 3: Spectra obtained with the four techniques used. The value in upper part of each panel represents the simulated range. In all panels the red represent the PE, blue LI, green ME, orange GF and black the model. Noticed how the four techniques are similar to the model.

The Figures 4 and 5 show the spectra computed for two aperiodic codes and the Table 1 shows the parameters used. Noticed how above 600km of range echoes from ESF are mixed with “ground clutter” and “ionospheric clutter”. The Figure 6 shows the spectra computed in presence (Left panel) of clutter and the resulting spectra after removing the clutter (Right panel).

Table 1: Parameters used in the simulations observed in Figures 4 and 5.

Code	Difference (a)	Spacing (d)	N	K	P	T_N/N	Diff. Min	Diff. Max	Sigma
AP	301.5 Km	4.5 Km	17	-	-	342.0 Km	306.0 Km	378.0 Km	0.0644
AM	301.5 Km	4.5 Km	7	2	7	315.0 Km	301.5 Km	324.0 Km	0.0285

Figure 4: The left panel show the original spectra obtained using PE. The spikes observed in the profile power are due to the ground clutter or/and ionospheric clutter. The aperiodic code used for this spectra is the same used to generated the Figure 3. The right panel show the same spectra but after of removing clutters.



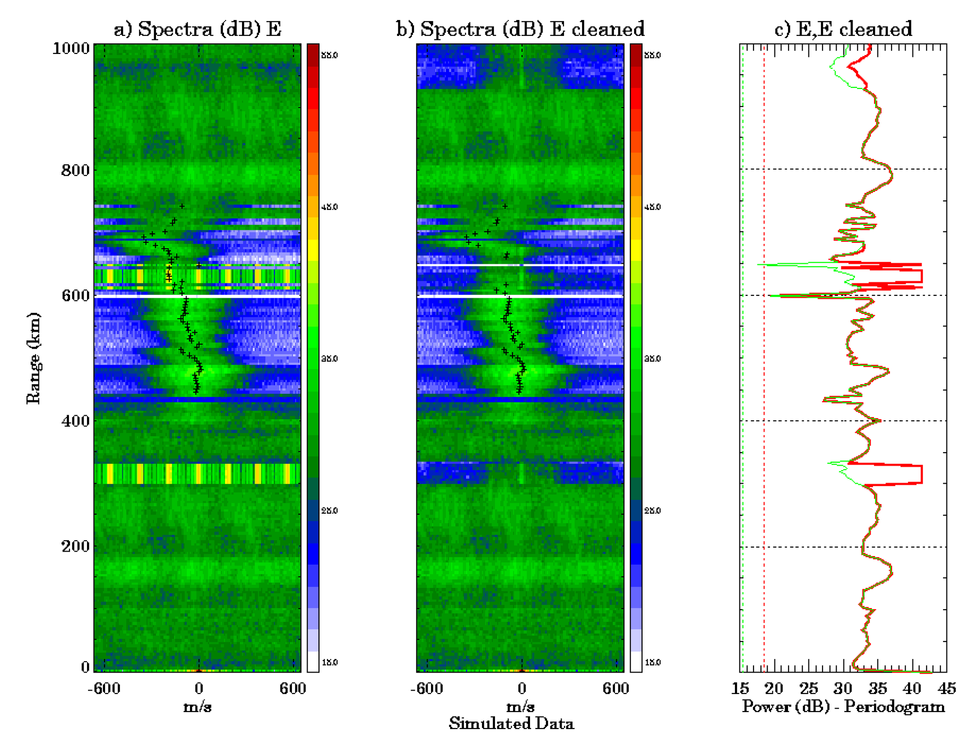
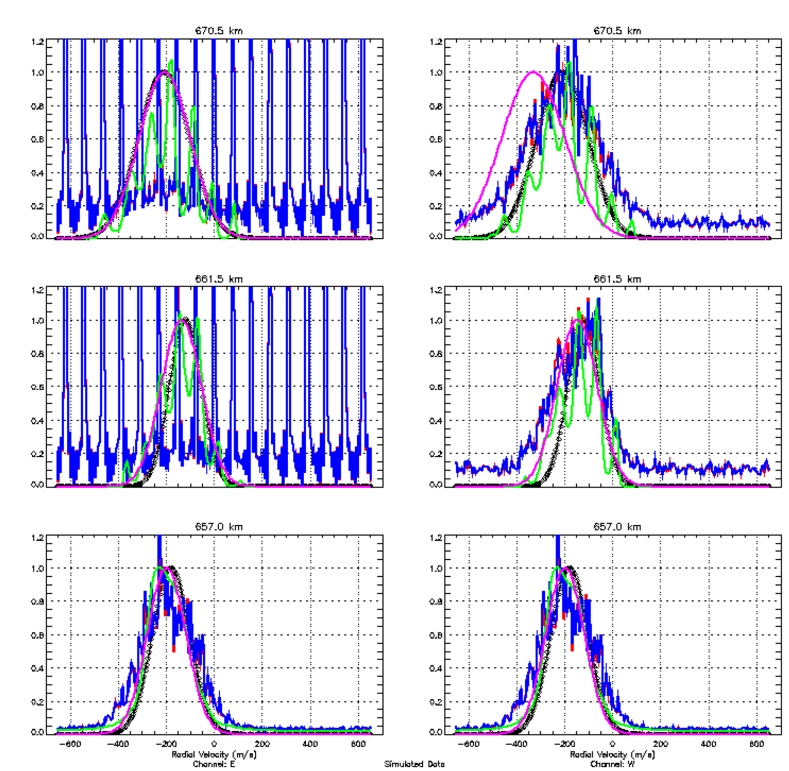


Figure 5: Similar to the Figure 4 but the spectra was simulated using an AM code. Noticed the different behaviour of the clutter.

Figure 6: Similar to the Figure 3 but the clutter is included in the spectra (Left panel). The right show the same spectra of the left side but after of removing the clutter.



Concluding Remarks

The Monte Carlo simulations was used in order to study the main characteristics of the inversion techniques and to evaluate different aperiodic codes. The analysis of the inversion techniques shows good results in the four cases when we do not consider clutter. PE and LI show better Doppler estimation in comparison with ME and GF, having ME a better results than GF. However the spectral width results show an opposite characteristic. That is ME and GF show spectral widths which values fit well with the model. PE and LI show spectral width much more broader than the model. In addition to the results presented above we can mention that results obtained from LI are very similar to the PE, the only one difference is the processing time. In all the spectra observed we could not see any big difference between both methods. Considering clutter in the simulated event, we have observed that ME gives quite good results, PE and LI failed but GF show good results (Failing in other case). The last can be justify due to the correlation time of the clutter.

The second analysis performed was the comparison between the different aperiodic codes. We compared AP and AM code, in both cases the result was similar without seeing a better estimation in one code. Both codes show spikes but the number of spikes depend of the number transmitted pulses and the width is inverse proportional to this number. In order to improve the result obtained for wide or narrow spectra we have analysed two case with spectral width of 100 m/s and 300 m/s, and the same Doppler. For the narrow case we have noticed that a sequence of 5 or 7 pulses with difference between the transmitted pulses of 306km or 297km can be used to sample the basic part of the Gaussian shape completely (See figure 7).

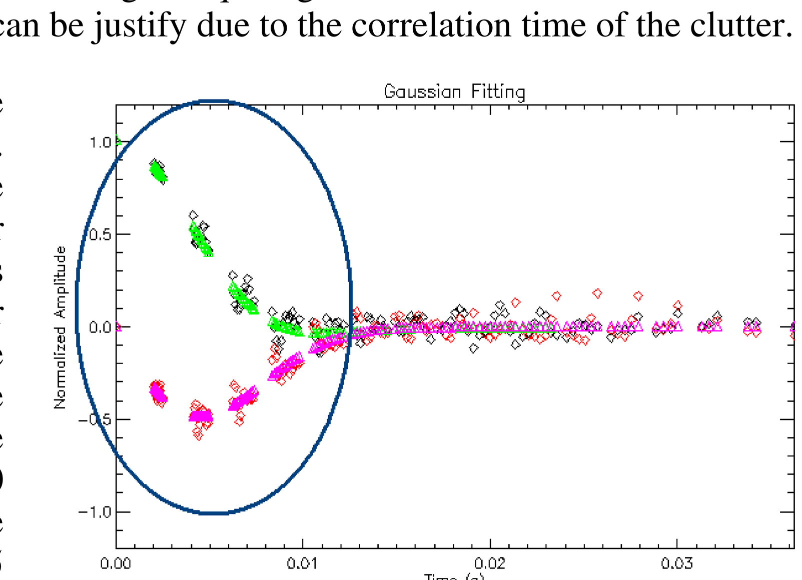


Figure 7: The part of ACF into the ellipse of blue colour is considered the basic part to define the ACF.

Using the same criteria for a wide spectra we can use a sequence of 5 o 7 pulses with a difference between pulses of 150km approx. The sequence lets us sample the completely Gaussian shape of the ACF. However due to the aliasing in range the samples from the ESF are easily contaminated.

Acknowledgement

We thank John Sahr for sending a copy of the Uppala thesis and let us clarify doubts about Lagrange interpolation.

References

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