Analysis of fit of K-distribution to CSIR sea clutter data

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Abstract: Sea clutter is the backscattered returns received by a radar system from the sea surface. Maritime radar signal processing has the ability partially to compensate for clutter to achieve effective detection of targets on or near the sea surface. This paper investigates the fit of the compound K-distribution model to sea clutter amplitude statistics; using data from a monostatic coherent X-band radar. This is completed on individual Doppler bins across the Doppler spectra taken from individual range gates. To evaluate the statistics of the sea clutter the distributions of the probability of false alarm (P_{FA}) from the sea clutter as a function of the detection threshold multiplier, α, have been analysed. The compound k-distribution has been fitted to the P_{FA} of the sea clutter across the Doppler spectrum. The variation of the P_{FA} with Doppler bin has been used to describe how the parameters of the backscattered sea clutter vary with the Doppler shift.

1 Introduction

Maritime radar research is a major, well established and continually relevant field in the area of radar research. For radar systems to operate in the complex cluttered environment that the sea represents requires good phenomenological understanding of the physical processes involved. This knowledge then needs to be integrated into mathematical models that are often themselves based on empirical observations. This shows the importance of good analysis of available sea clutter datasets. This analysis allows radar engineers accurately to predict and to improve the system performance of radars in the maritime environment.

The main aim of this research is the analysis of coherent radar data focusing on the statistical nature of the sea clutter present within it with the objective of improving radar performance. The data was taken from the CSIR 2006 OTB 2006 Measurement Trial, which can be seen in [1]. These measurements were taken using a calibrated, coherent, staring, pulsed radar system at frequencies ranging from 6.9 GHz to 10.3 GHz, from which we have taken some of the X-band data.

The approach to investigate the sea clutter present in the data available was to fit the compound K-distribution model, including taking account of the effect on the statistics of the thermal noise in the data, to sea clutter amplitude statistics, with these main aims.

- Demonstrate the variation of the fit across the Doppler spectrum of the compound K distribution, with and without taking into account thermal noise. Using data from a single range gates Doppler spectra and comparing this with the power spectral density.
- Analyse the difference between the resultant fits of the K-distribution that incorporates the presence of thermal noise and the more simplified model that does not take this into account.
- Confirm the validity of previously published work [2] that used a different data to further validate these previous finding.

2. Theory

Simple Gaussian based models were first used to represent the sea clutter returns in radar systems. This was found to be insufficiently effective in predicting the clutter returns as radar systems range resolutions were increased, especially for low grazing angles. These developments lead to more complex statistical models being applied to characterize the sea clutter.

These scattering models can be used to compare with the sea clutter present in the data using Probability of False Alarm (P_{FA}) curves. Evaluation of these curves makes it possible to define what P_{FA} the radar system will experience for a given threshold level. This defines the radars sensitivity to the sea clutter and is used for CFAR processing.

2.1 Compound Sea clutter model

The compound K-distribution model is now a well establish model originally applied to sea clutter by Jakeman and Pusey [3]. The model has been found to be effective for modelling sea clutter at higher spatial resolutions, by taking into account both the underlying modulation due to the waves and the additional speckle component [4].

The method used to evaluate the sea clutter statistics was to evaluate the sea clutter present in the data and compare it to the K-distribution. To do this the Probability of False Alarm (P_{FA}) vs. threshold multiplier plots from the data were compared to the compound K distribution sea clutter model P_{FA} curves. The probability that the envelope exceeds some threshold E_T, and hence the probability of false alarm, is given by,

$$\text{Prob}(E > E_T) = \int_{E_T}^{\infty} dE\, P(E) = \exp\left(-E_T^2/\langle I \rangle\right) \qquad [1]$$

Where E_T is the set threshold and $<I>$ is the mean intensity of the returned sea clutter. For the K-distribution that does not take into account the thermal noise present the P_{FA} can be shown to follow the relation seen in Eqn. 2.

$$P_{FA} = \frac{2(\alpha\nu)^{\frac{\nu}{2}}}{\Gamma(\nu)} K_\nu(2(\alpha\nu)^{\frac{1}{2}}) \qquad [2]$$

Where α is the threshold multiplier, ν is the shape parameter of the distribution, and Γ and K_ν are gamma and Bessel functions respectively. When thermal noise is then included in the K-distribution the PDF is then defined by Eqn. 3.

$$P(E|p_n, b, \nu) = \frac{2E\,b^\nu}{\Gamma(\nu)} \int_0^\infty \frac{x^{\nu-1}\exp(-bx)}{x+p_n} \exp\left(-\frac{E^2}{(x+p_n)}\right) dx \qquad [3]$$

Eqn. 3 does not have a close form analytical solution. Therefore a numerical solution was required to evaluate the K-distribution + thermal noise. This was completed using an algorithm published by G. Davidson [5].

To produce the P_{FA} distribution of the sea clutter present in the data a Probability Density Function (PDF) of the sea clutter amplitude values was generated. The cumulative summation of this PDF plot can then be used to define the P_{FA} plot of the data.

The shape parameter varies depending on how 'spiky' the sea clutter distribution is, it can take values between $0.1 \leq \nu \leq \infty$. As the shape parameter reduces the sea clutter present is increasingly 'spiky', with more frequent large returns present within the amplitudes.

3. Results

3.1 Individual Range gate Time-Doppler Spectra

The raw time-Doppler data has been used to show the variation across all the Doppler bins in single range gate over a period of time, an example of this can be seen in Fig. 1.

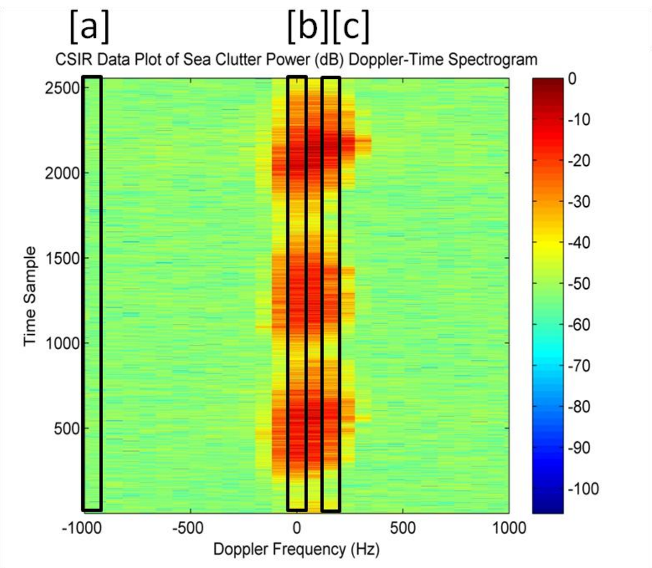


Fig. 1 Time Sample Doppler Power Spectra Density from single range gate

This was generated by first applying a Dolph-Chebyshev -55dB Doppler side lobe weighting, then completing a 64 point short time FFT. The statistics of the returns from each individual Doppler bin was then analysed and compared to the K-distribution; with and without taking into account noise.

This was done by fitting the P_{FA} curves generated from each Doppler bin to a K-distribution with a given shape parameter. Examples of P_{FA} plots from selected Doppler bins, seen in Fig. 1, that have been fitted to the K distribution can be seen in Fig. 2. The method of fitting was a least mean square difference calculated in the $\log(P_{FA})$ domain. The fitted shape parameter was found to represent a Noise-like distribution at the very edge of the spectrum [A], a spiky distribution at the edge of the sea clutter spectrum [C] and a less-spiky distribution in the centre of the spectrum [B].

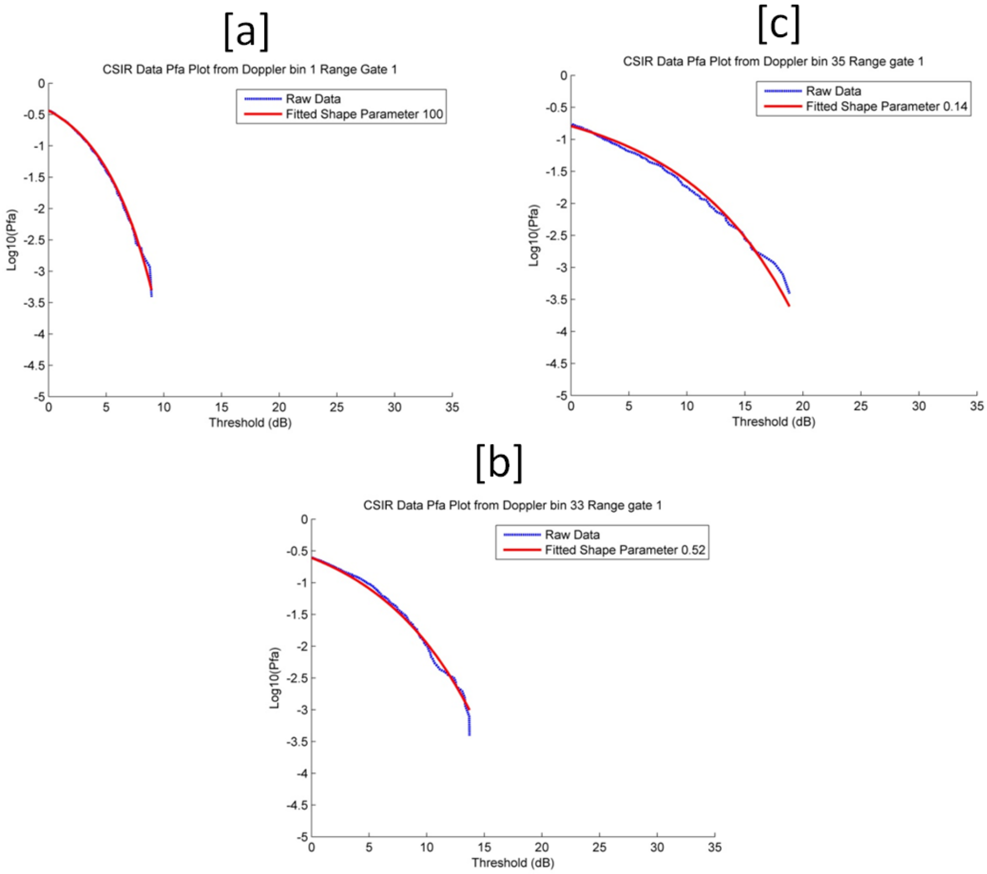
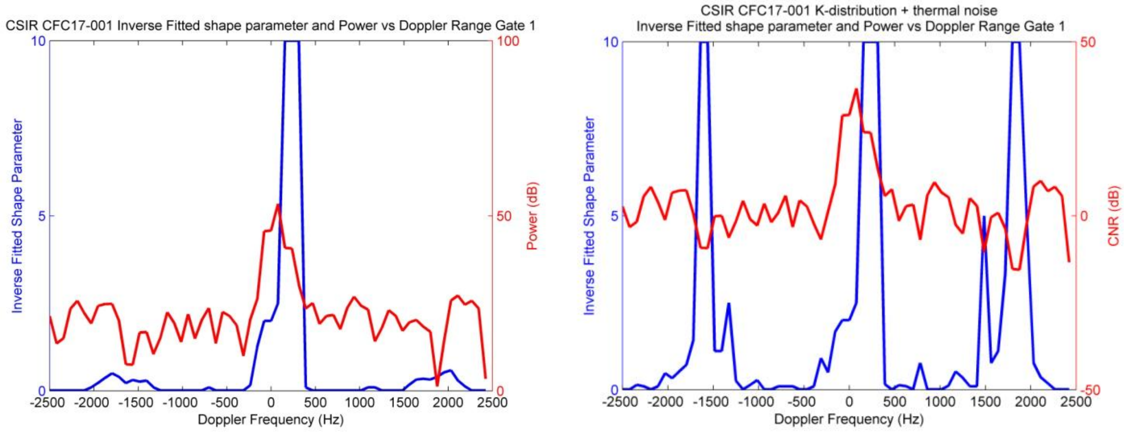


Fig. 2 Fitted K-distribution to Doppler bins 1, 33 and 35 corresponding to [A], [B], and [C] respectively

This is in agreement with what has been found before [2, 4] and provides further evidence that those results are representative of the typical behaviour of the clutter.

The variation of the inverse of the fitted shape parameters with Doppler is shown alongside the sea clutter power spectrum in Fig. 3. The fit has been performed under two different assumptions. The simpler assumption is that the data consists only of K-distributed clutter, but the more sophisticated fit recognises that at the edge of the clutter spectrum (case [c] above) the contribution to the total power from the thermal noise should not be ignored. The distribution appears to be asymmetrically more spiky, in this data set, on the positive Doppler side in comparison with the power spectra.



a)

Fig. 3 Inverse Fitted shape parameter and Power plotted against Doppler for a) K-distribution without noise

The most prominent difference is the high shape parameters seen around +1800Hz and -1800Hz, but unfortunately these are artefacts of the data, the clutter seen here being duplicates of the true spectrum, moved into these bins by inadvertent modulation on the radar transmissions. The fact that the high shape parameters are seen here is, however, an indication of the sensitivity of this technique.

More significant for the phenomenology of the clutter, however, is the greater detail which is apparent in the spikiness data at around -300Hz.

4. Conclusions.

The CSIR Data has shown a good fit to a compound K-distribution with a variation of shape parameters across the Doppler spectrum. The analysis has provided confirmation of the previous observations that the distribution of the sea clutter at Doppler shifts at the edge of the clutter spectrum is more "spiky" clutter than at the centre.

Taking account of the presence of the thermal noise is seen to improve the information which is available about the clutter spikiness.

Future work will involve analysing more data to be able to start to produce models of how the spikiness in different Doppler bins changes with parameters such as Grazing Angle, Range Resolution, and Meteorological Conditions.

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