Hardware in the Loop Testing and Evaluation of Seaborne Search Radars

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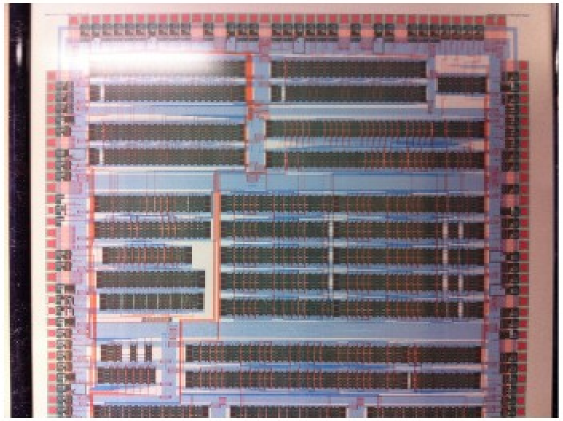
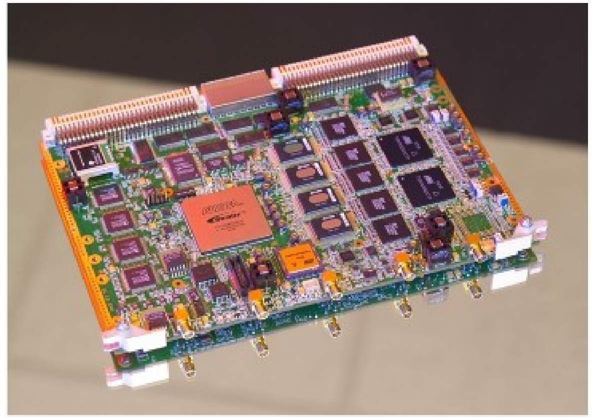
Outline

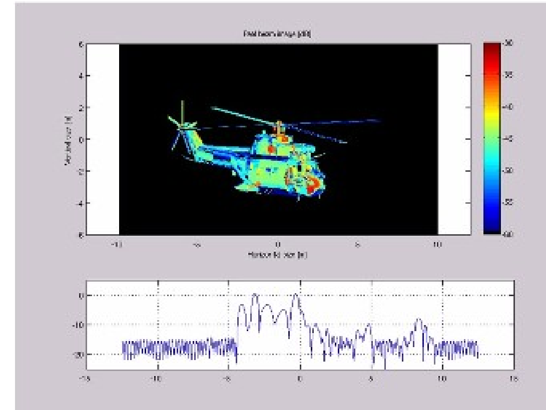
- Introduction to CSIR DRFMs
- Introduction to hardware in the loop testing and evaluation of radar systems
  - DRFM hardware history
  - Integrated capability, RCS modelling, Scenario simulation,
- The clutter problem
- Sea clutter - the most complex case
- Modelling sea clutter - K Distribution (why the K distribution)
- Sea clutter measurements
- Simulating a single range line
- Using time multiplexing to simulate a 360 degree scenario
- Technological tradeoffs

Where we are from: South Africa

Digital Radio Frequency Memory History



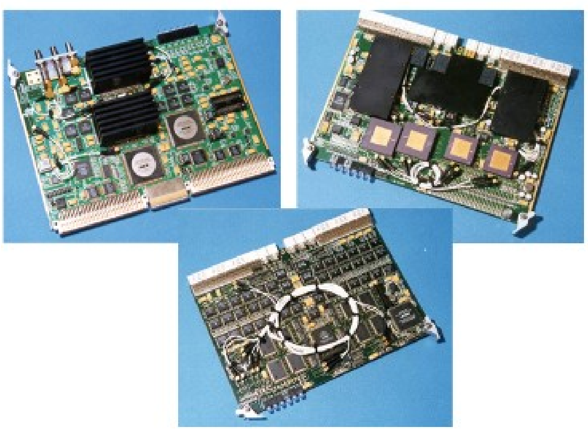


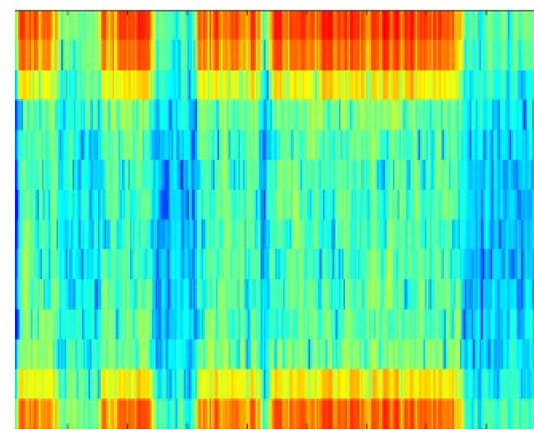


199x	1999	2004	2007	2009	2010	2012

DRFM Technology Development Projects

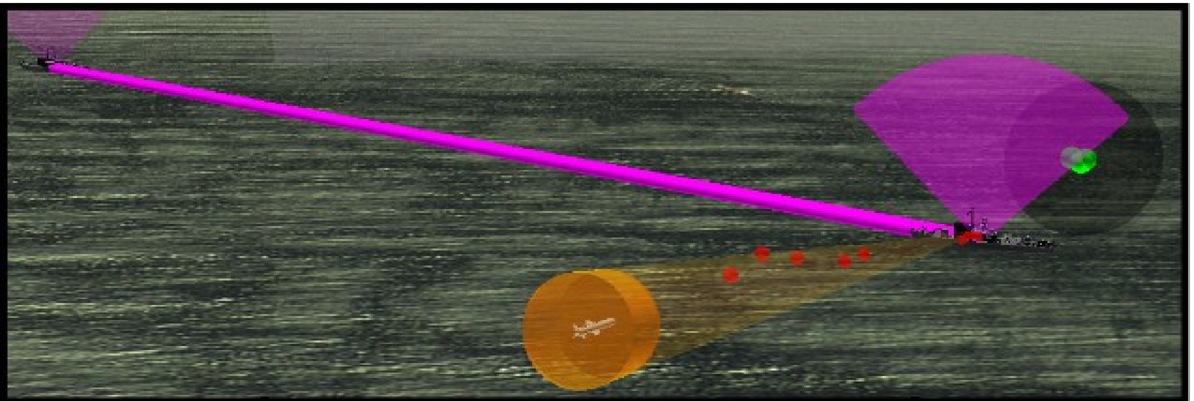
1st Gen	2nd Gen	3rd Gen	4th Gen	Complex targets	Clutter	5th Gen
IBW:	400 MHz	500 MHz	800 MHz			2 GHz



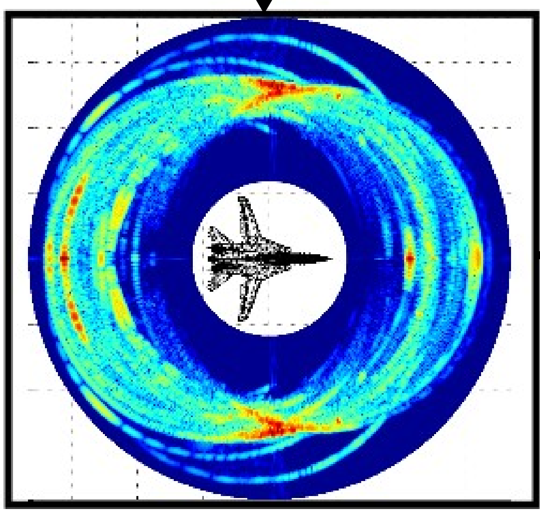


Integrated capability

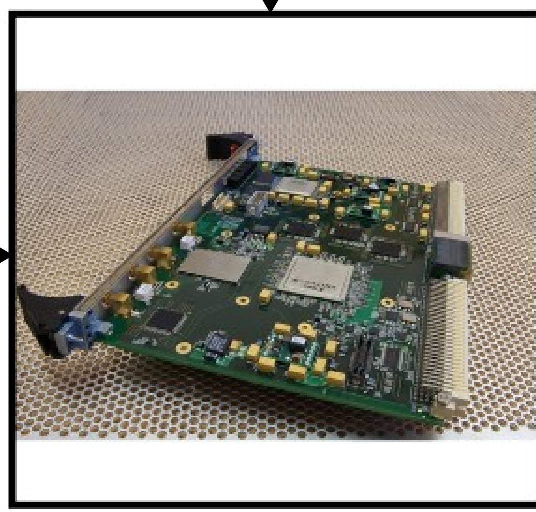
Scenario simulation & control



System under test



RCS / HRR prediction



HIL simulation

Radar under test

Radar Environment Simulation

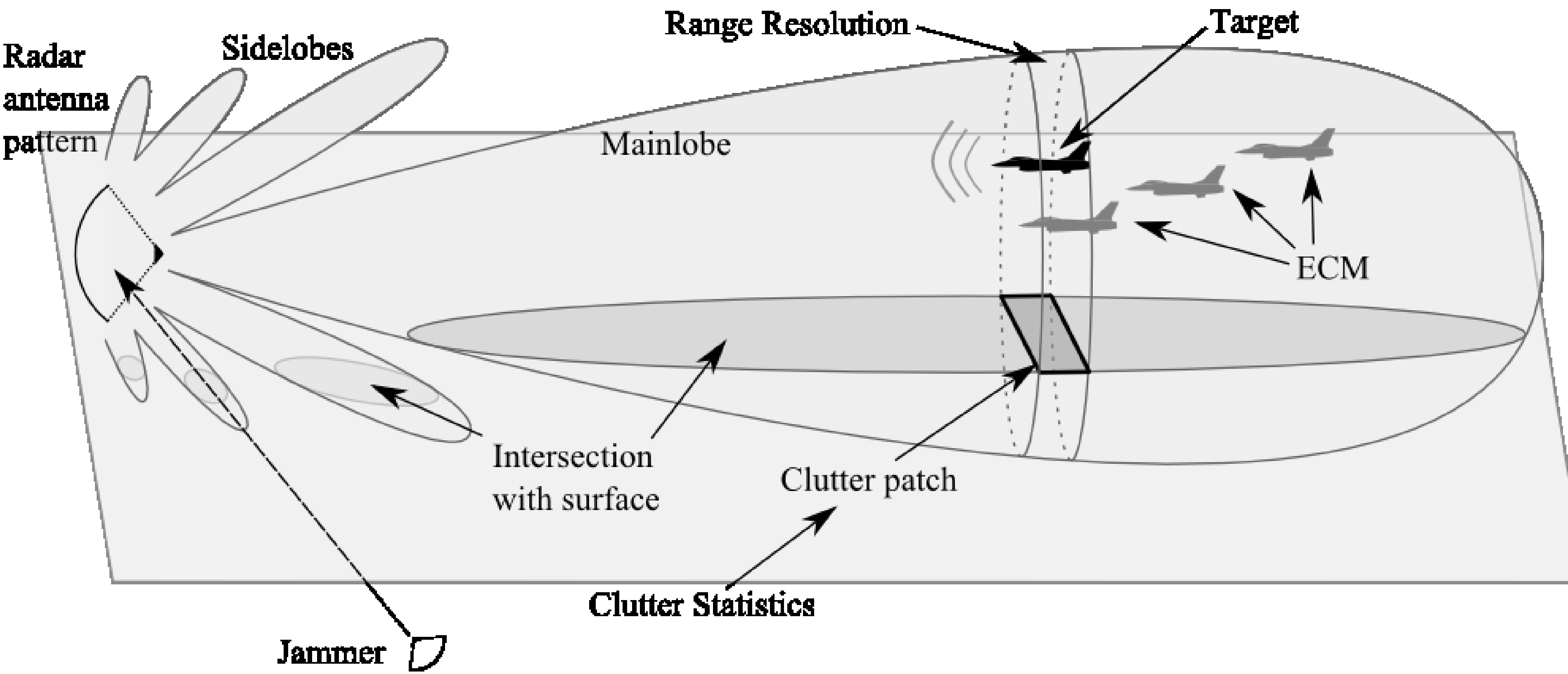
Advances in DRFM technology allows for the real-time simulation of a wide range of targets, ECM techniques, and environmental effects (see reference [3])

Radar Environment Simulation

- **Target Simulation**
  - Point targets
    - Multi scatterer targets
- **Electronic Attack**
  - Jamming
- **Target Environment**
  - **Clutter**

[3] J.J. Strydom, J.E. Cilliers, M. Gouws, D.M. Naicker, K. Olivier, "Hardware in the loop radar environment simulation on wideband DRFM platforms," IET radar conference 2012.

Radar Environment Context

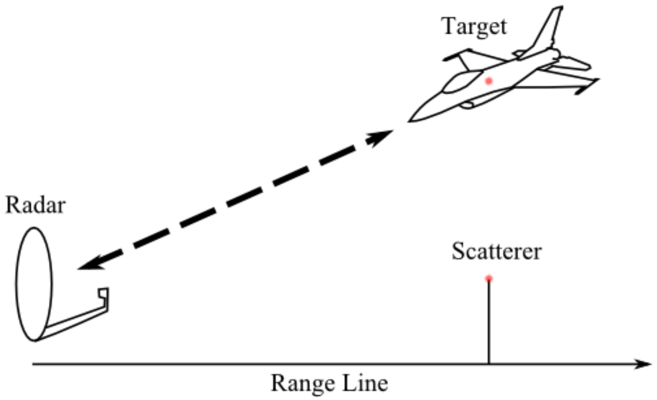


ECM

- Deception techniques to interfere with target detection and tracking
- Non-coherent jamming (injection of high powered noise)
- Manipulation of transmitted radar pulse
  - Range
  - Doppler
  - Amplitude information
- Goal is to have radar interpret false target as actual target
- Common ECM techniques for tracking radar
  - Range gate pull off
  - Velocity gate pull off

Complex Targets

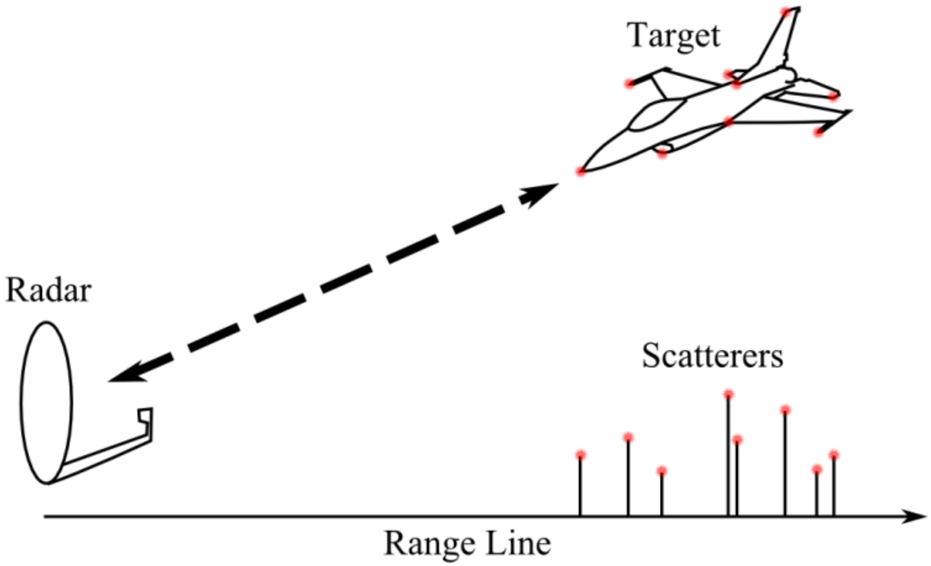
- DRFM simulates a target by simply re-transmitting the radar pulse
- Approximate target as a single scatterer
- Assumption is made that radar target is only present in a single range cell of the radar

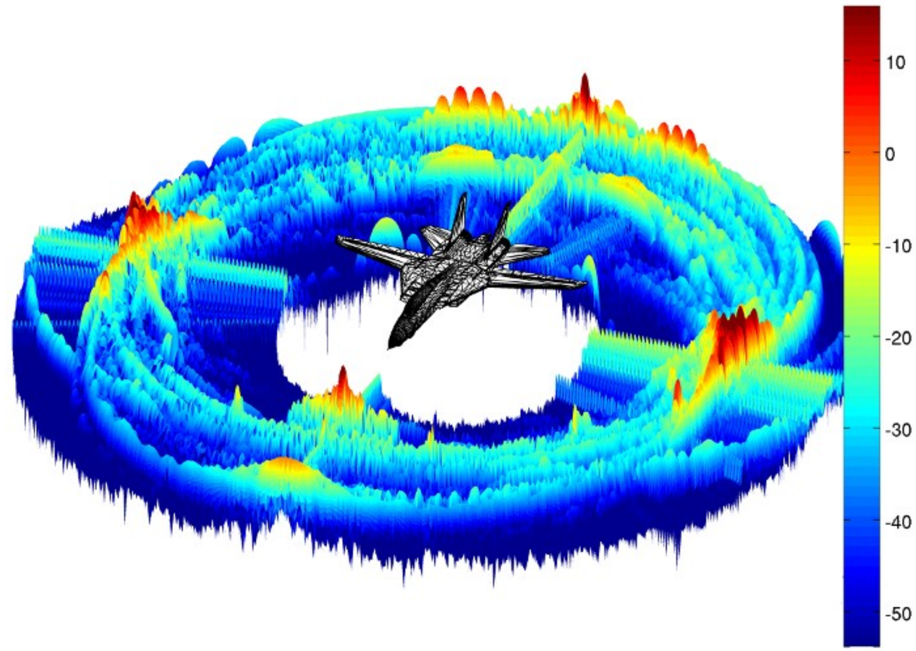


- Today's radars use High Range Resolution (HRR) profile techniques
- Separation of scattering points on a single target
- This creates a "complex" target return
- Can be used for Non-cooperative target recognition (NCTR)

Complex Targets

- High Range Resolution target profile [1]





[1] J.C. Smit, J.E. Cilliers, E.H. Burger, "Comparison of MLFMM, PO and SBR for RCS Investigations in Radar Applications," IET radar conference 2012.

Clutter

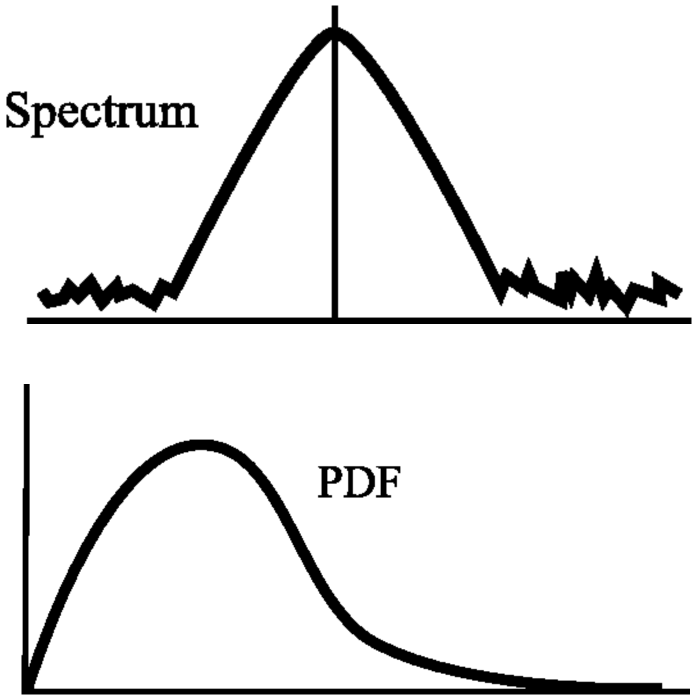
The Problem:

- Clutter returns interfere with the object of interest (target)
- Operation in clutter is a critical aspect of the radar's performance
- Real world testing of a radar against all types of clutter for all possible types of scenarios is costly and difficult to re-create
- Software simulation cannot take all the finer details of the complete design and implemented system into account
- Severely limited with software simulation if you are required to verify a radar purchased from a 3rd party

Clutter from literature

Considerations for high fidelity clutter generation

- Clutter Radar Cross Section (RCS)
- Number of discrete scatterers
- Spatial extent of clutter
- Velocity extent of clutter (Doppler spectrum)
- Wavelength dependence
- Amplitude distribution
- Spatial correlation
- Polarization properties

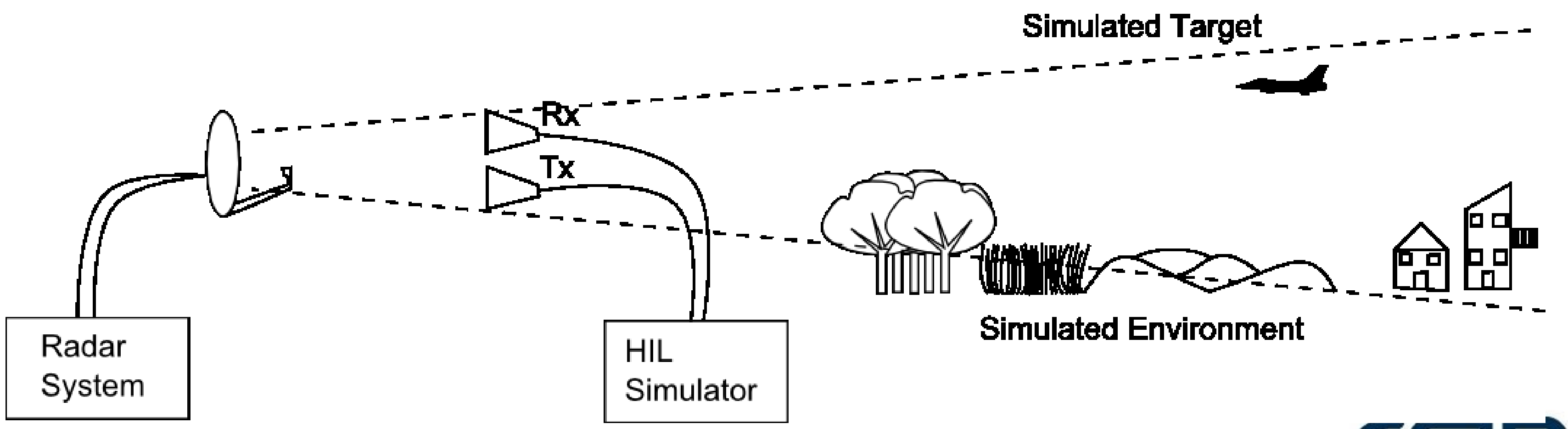


(From D.K. Barton, "Modern Radar System Analysis")

Radar Clutter Simulation

The Solution:

- Hardware in the loop simulation on DRFM based hardware
- Statistical modelling of clutter, NOT recorded data
- (Playback of recorded data is radar and configuration dependent)



Radar Clutter Simulation

Advantages of this approach:

- Cost effective
- Test many different scenarios relatively quickly
- Repeatability of experiment with the same parameters
- DRFM approach to Hardware in the loop simulation is **radar independent**

Sea Clutter Simulation

Current research:

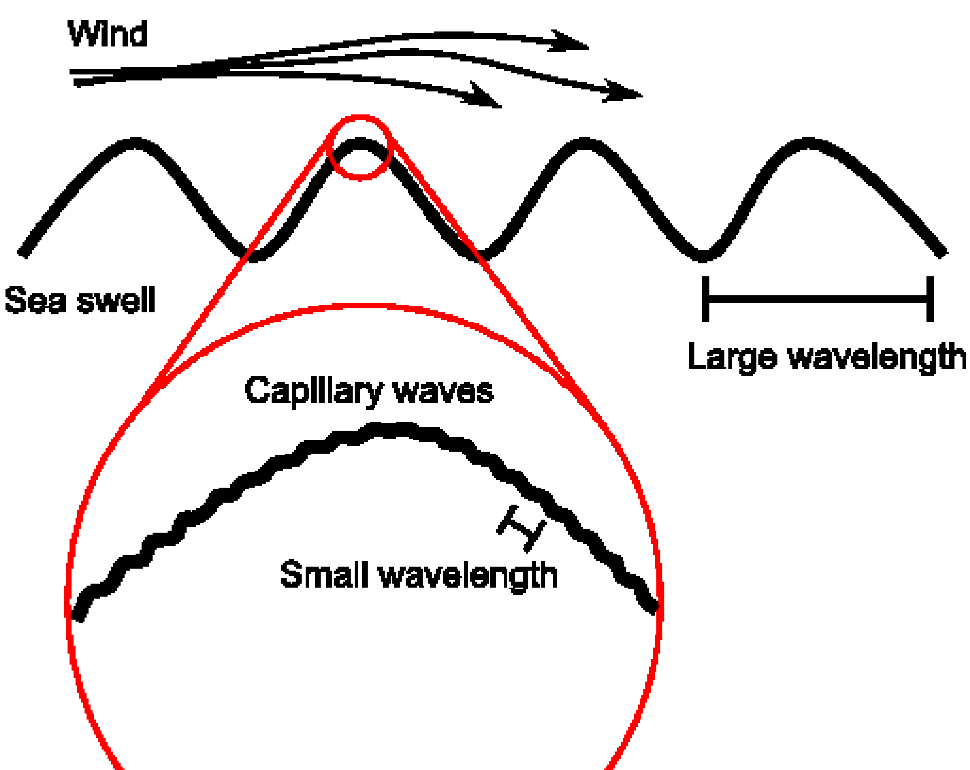
- Clutter simulation from a seaborne platform

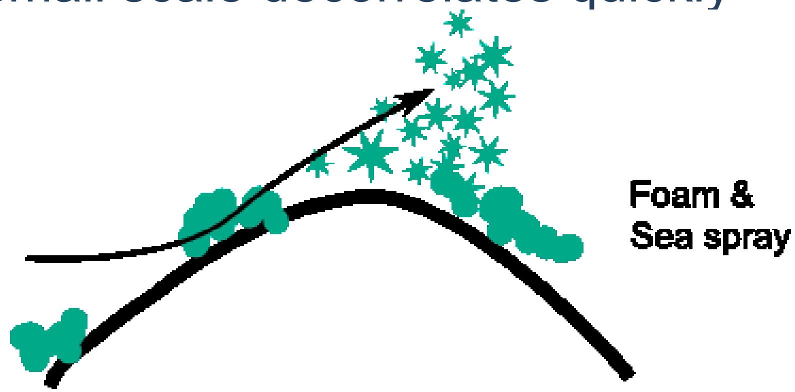
The Challenge:

- Sea clutter statistics not straightforward to connect to sea environment, there are no good solutions in literature as of yet
- Clutter statistics are dependent on many variables (wind direction and magnitude, wave direction and magnitude, water depth, etc.)
- Many different scattering mechanisms, complex models

Sea Clutter Simulation

- Scattering mechanisms for sea clutter have large and small scale
- Spiky nature of clutter caused by the small scale scattering mechanisms: ripple, spray and foam.
- Large scale (swell) decorrelates slowly, small scale decorrelates quickly





Sea Clutter Simulation

Compound model for sea clutter:

- Texture (tau): non-negative random process; takes into account the local mean power (large scale)
- Speckle (x): complex Gaussian process, takes into account the local backscattering (small scale)

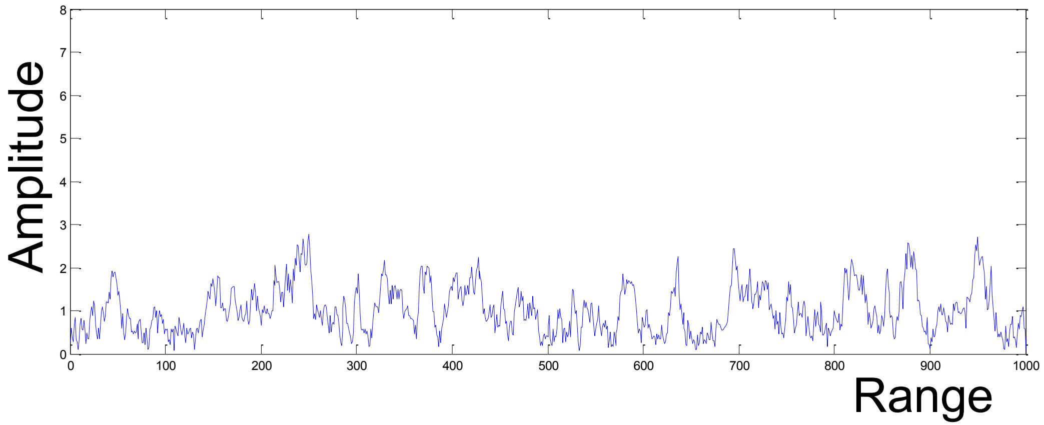
$$z(n) = \sqrt{\tau(n)}x(n)$$

- For a Gamma texture the K distribution results (amplitude PDF):

$$p_R(r) = \frac{\sqrt{4\nu/\mu}}{2^{\nu-1}\Gamma(\nu)}\left(\sqrt{\frac{4\nu}{\mu}}r\right)^{\nu} K_{\nu-1}\left(\sqrt{\frac{4\nu}{\mu}}r\right)u(r)$$

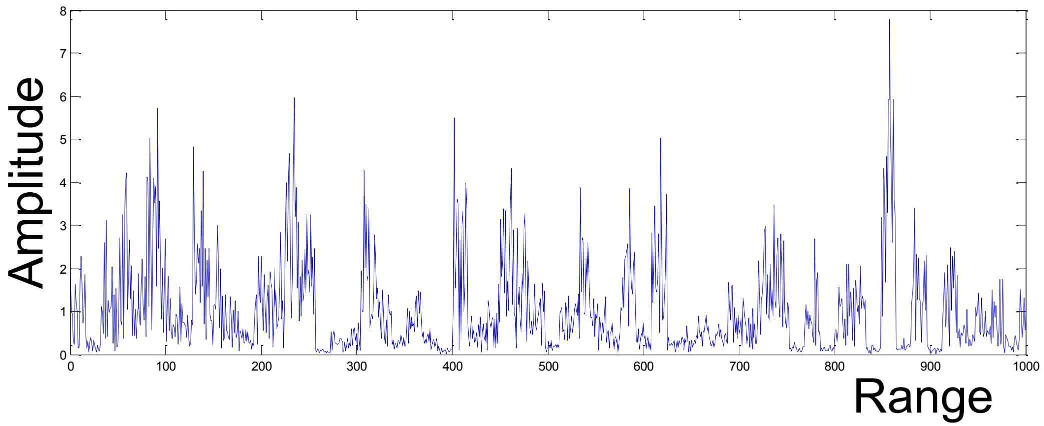
Synthetic Clutter Simulation

Rayleigh distributed clutter



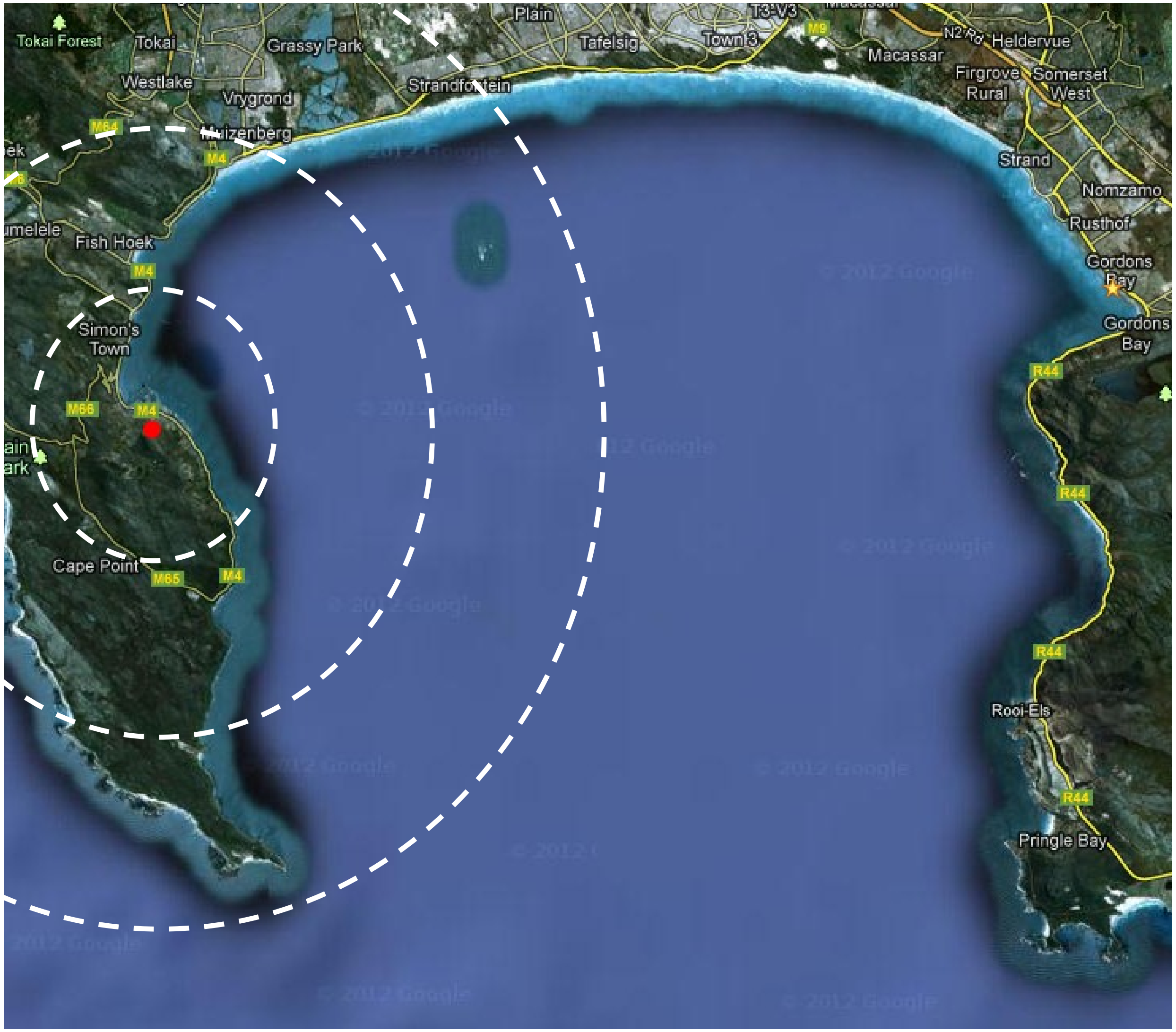
- Sufficient for low resolution radars and for large grazing angles
- Many scattering points in a range cell cause Gaussian statistics
- Magnitude of a Gaussian signal is Rayleigh

K distributed clutter



- K distribution represents sea clutter statistics
- Sea clutter is more spiky
- Fewer scattering points in a range cell causes more spikes

Sea Clutter Measurements



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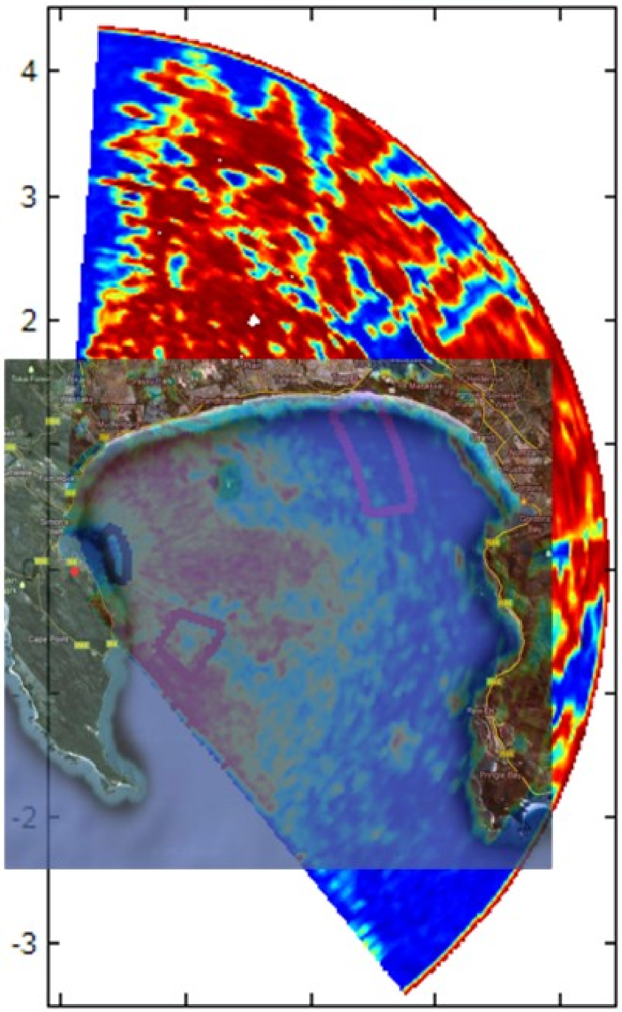
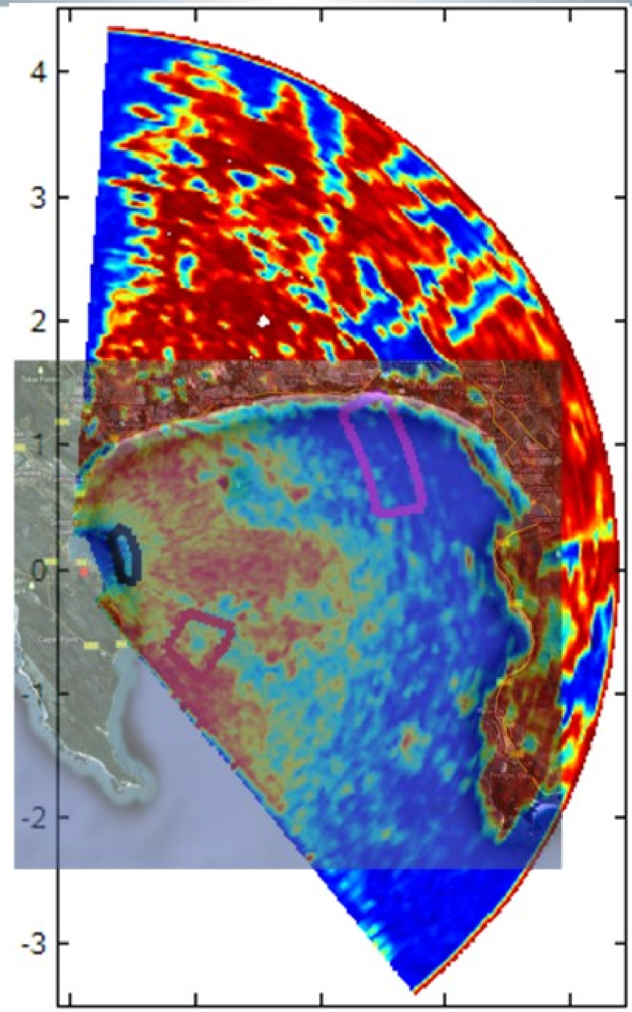
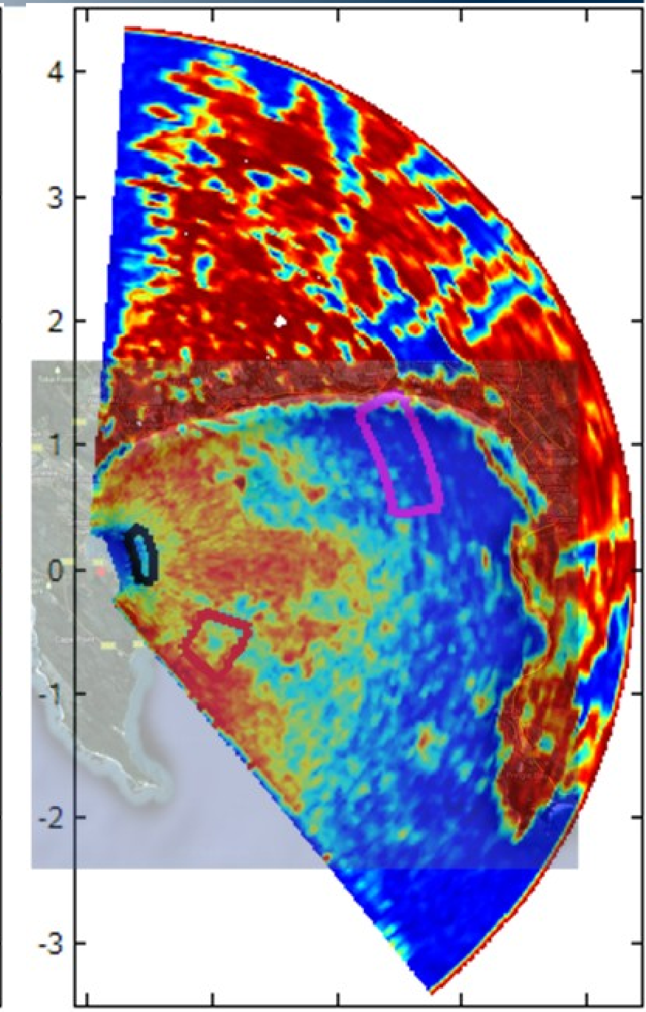
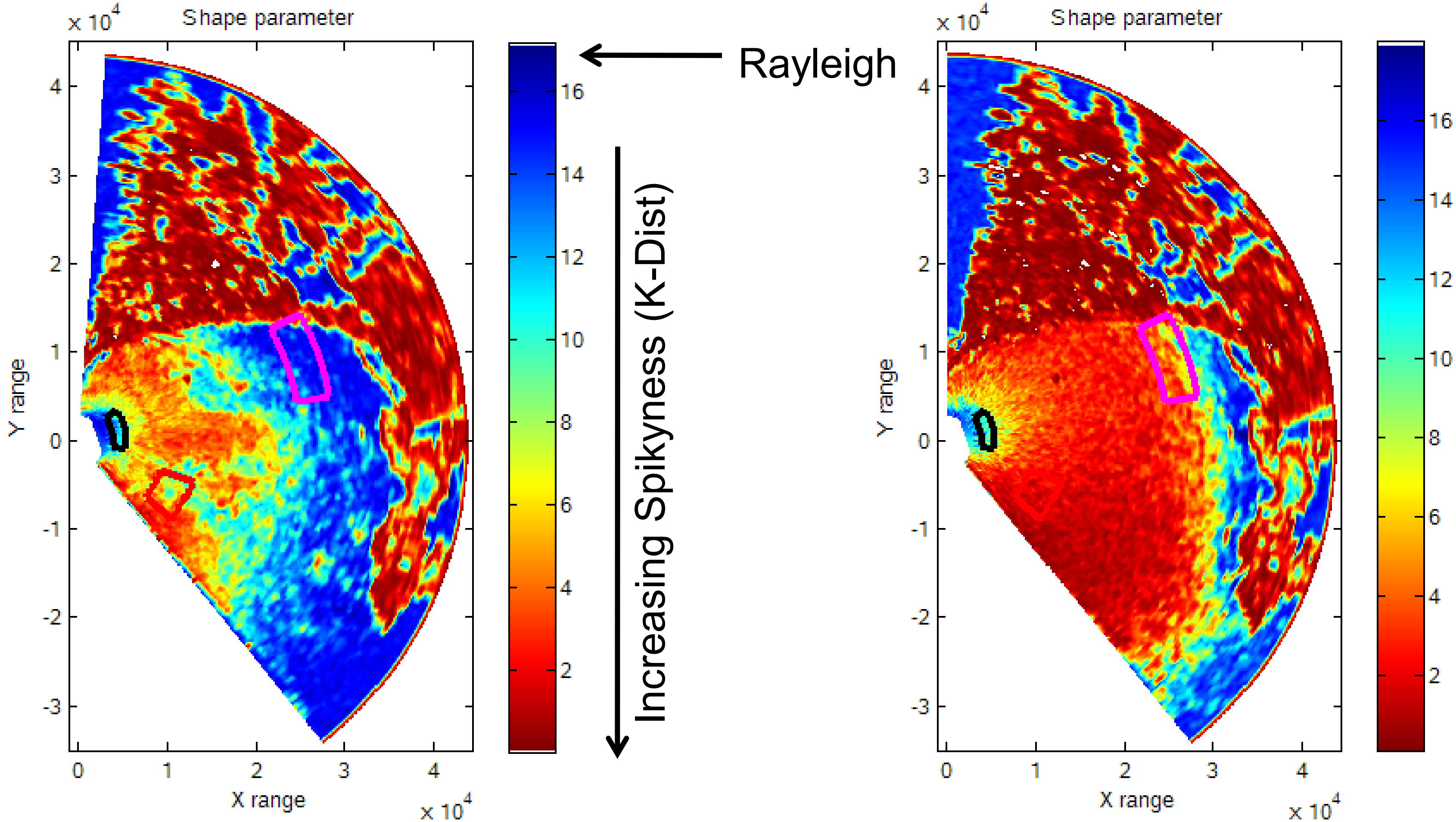
Sea Clutter Measurements







Sea Clutter Measurements [2]



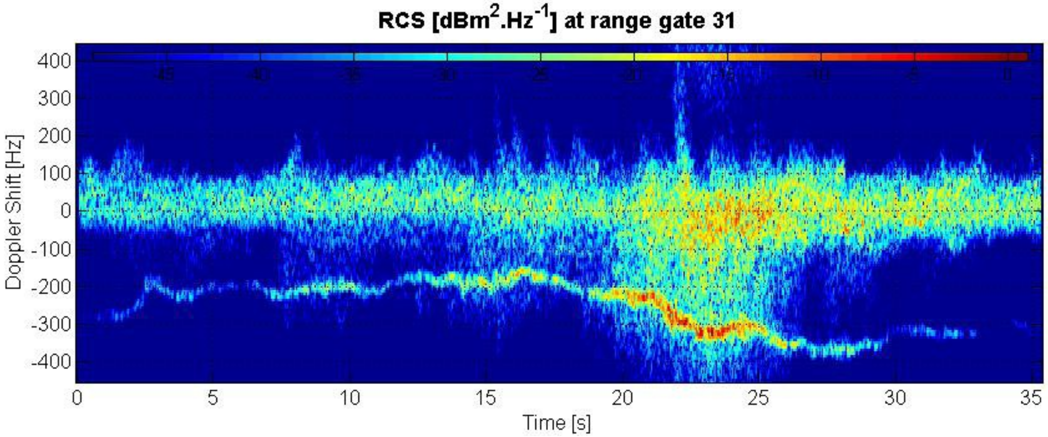
Low sea state

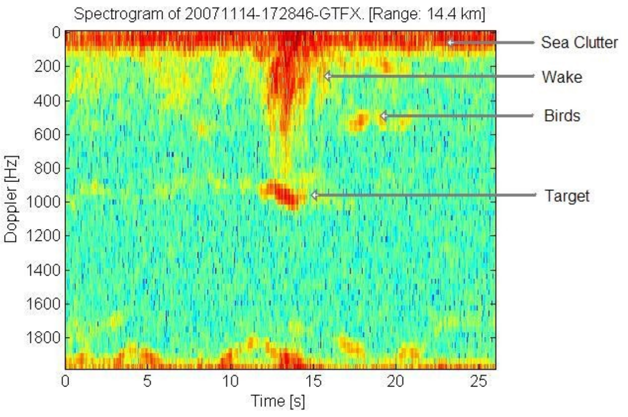
High sea state

[2] A. McDonald, J.E. Cilliers, "Autoregressive-to-anything process model of maritime clutter and targets," IET radar conference 2012.

Sea Clutter Measurements [4]

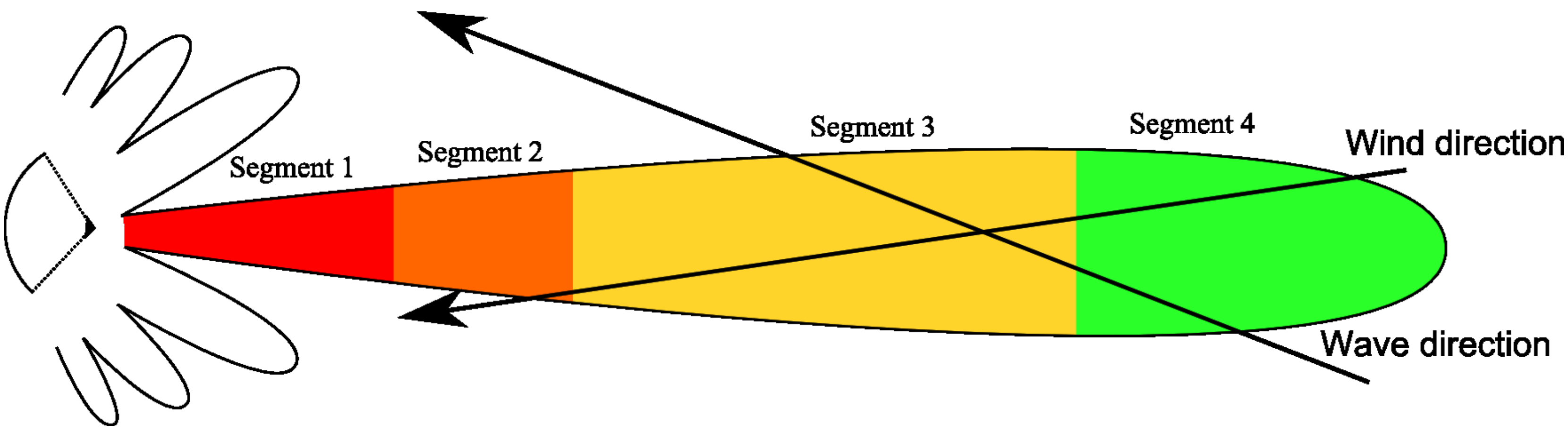
- On-line database freely available of small boats in sea clutter
  - Radar data database of this quality and size are very rare
  - Very well instrumented targets in sea clutter
  - Database is well documented in a user guide
  - Aim is small boat detection in sea clutter
  - Over 100 users from over 16 countries
  - Did I mention it is free?
- **Available at:** http://www.csir.co.za/small_boat_detection/





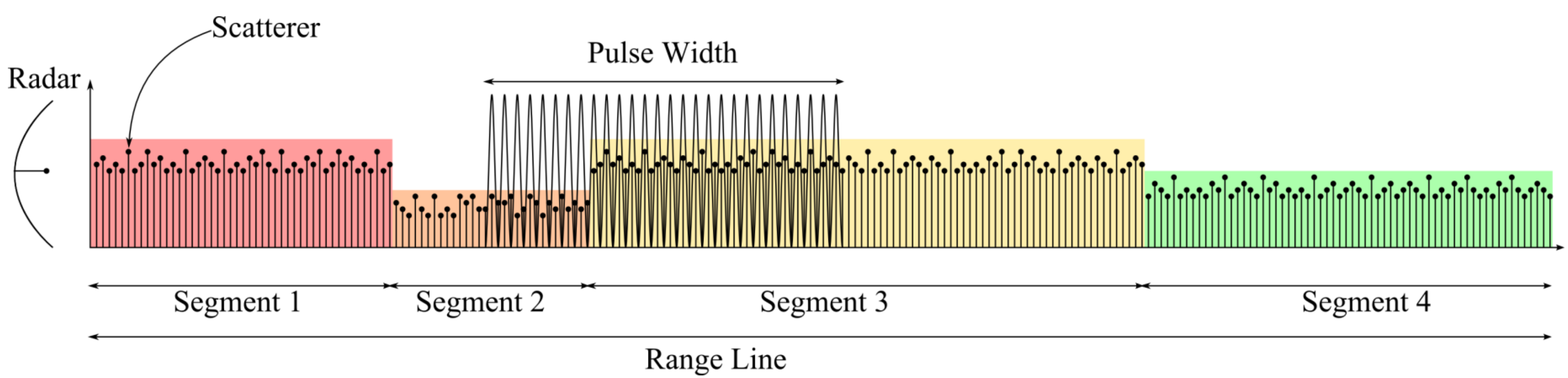
Synthetic Clutter Simulation

- Wind and wave direction does not change relative to radar because of the constant look angle
- Statistics remain constant
- Range line can be divided up into range segments to re-create the change in properties of the sea surface with range



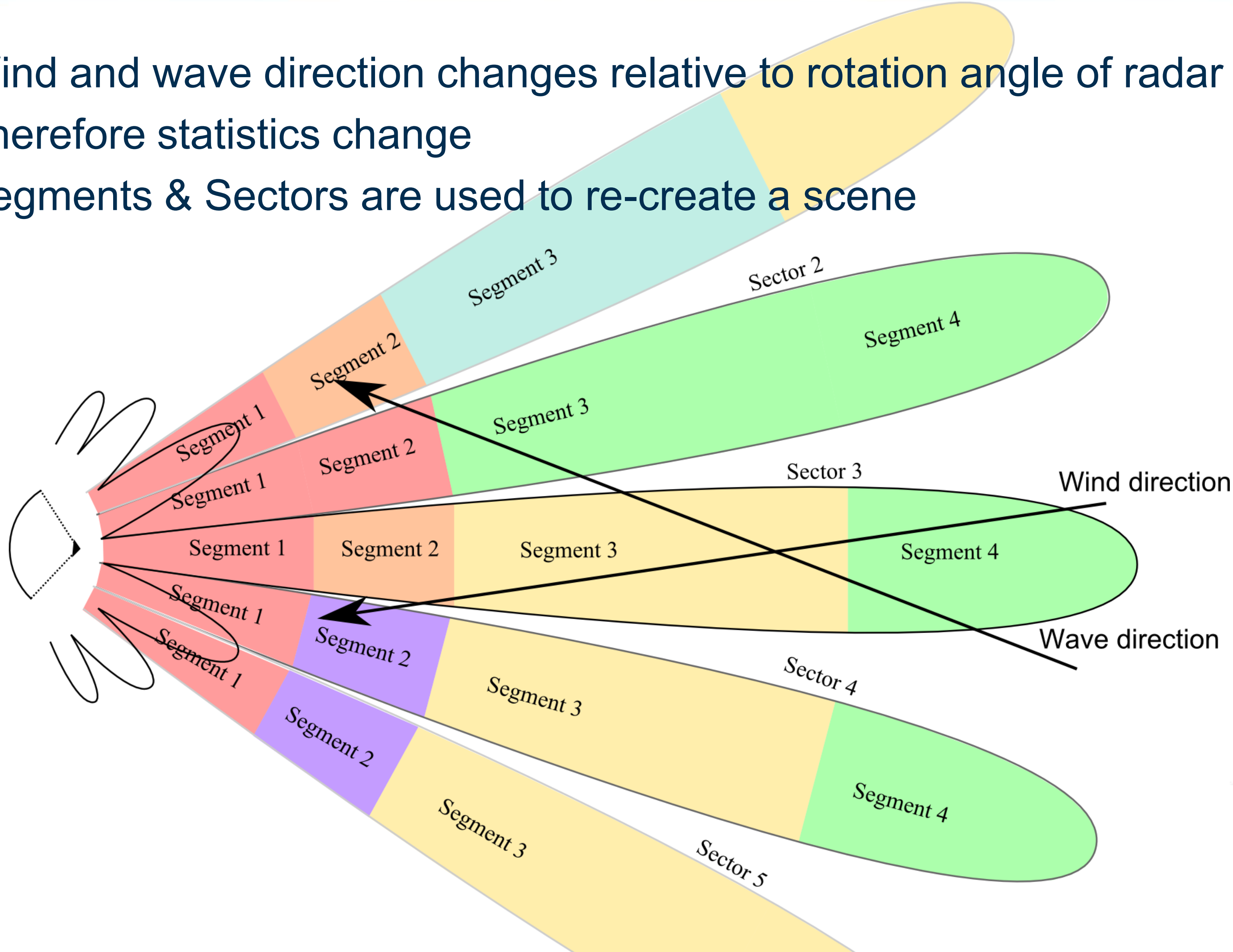
Synthetic Clutter Simulation

- Segments contain an arbitrary number of time correlated scatter points
- Each segment is set independently of the other segments
- Each segment has is own statistics
  - Amplitude
  - Spectrum
  - Probability Density Function (PDF)
- All segments combine to produce a single range line



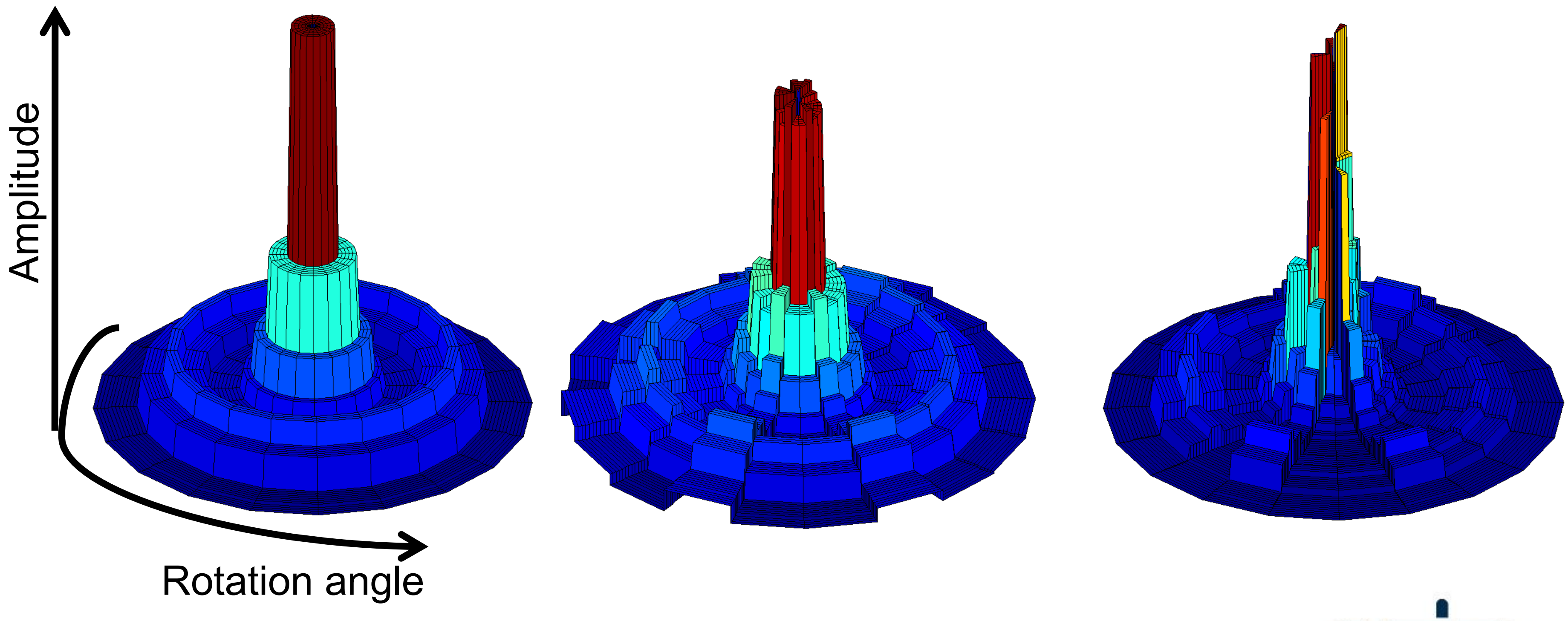
Synthetic Clutter Simulation

- Wind and wave direction changes relative to rotation angle of radar
- Therefore statistics change
- Segments & Sectors are used to re-create a scene



Synthetic Clutter Simulation

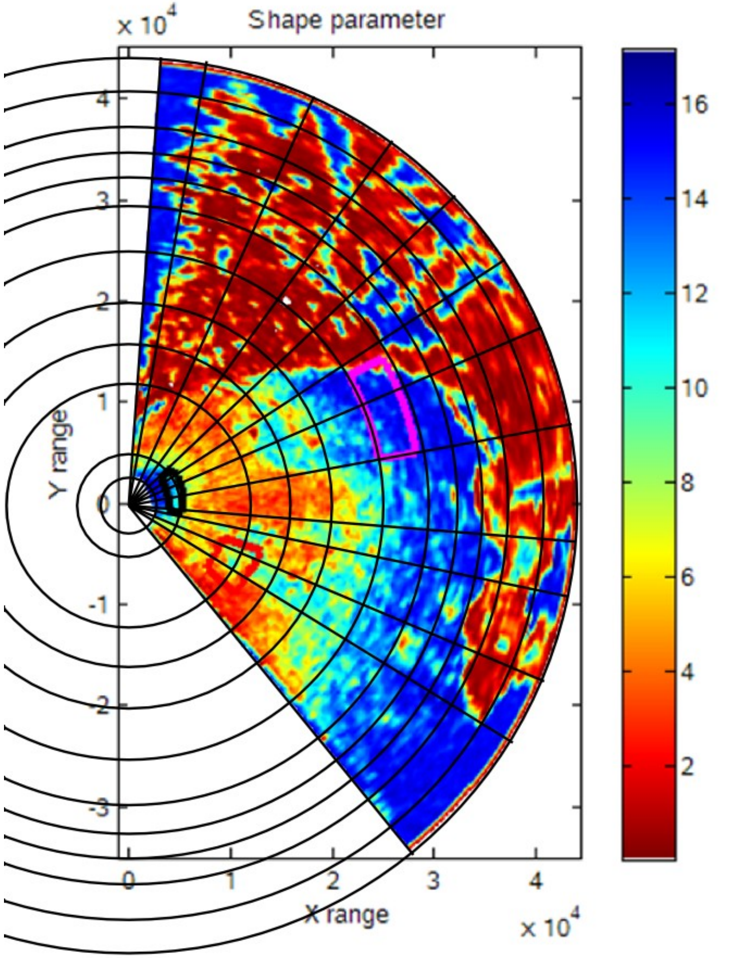
- Time multiplexing can be used to create a 360 degree scenario

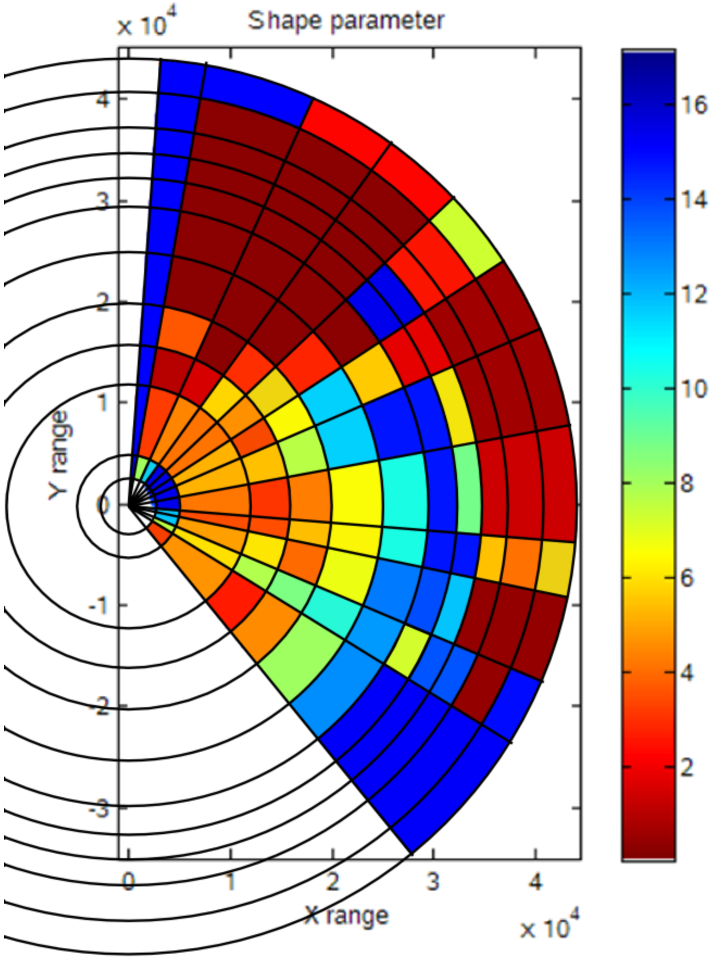


Synthetic Clutter Simulation

- Time multiplexing can be used to create a 360 degree scenario
- Scenario divided into sectors based on desired statistics in that direction
  - Divisions based on regions of similar statistical properties
  - Divided in a statistically meaningful way
  - For example :1 sector of 80 degrees for an area looking at a mountain and 35 sectors of 8 degrees to capture the sea surface with the relative wind and wave direction changes

Synthetic Clutter Simulation





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Synthetic Clutter Simulation

Technological tradeoffs:

- Bandwidth spectral shaping quality and accuracy
- Fidelity of clutter (number / update frequency, of clutter samples)
- Complexity of statistical distribution shape
  - Rayleigh (least complex)
  - Weibull (medium complexity)
  - Log-Normal (medium complexity)
  - K-Distribution (most complex)

References

1. J.C. Smit, J.E. Cilliers, E.H. Burger, "Comparison of MLFMM, PO and SBR for RCS Investigations in Radar Applications," IET radar conference 2012.
2. A. McDonald, J.E. Cilliers, "Autoregressive-to-anything process model of maritime clutter and targets," IET radar conference 2012.
3. J.J. Strydom, J.E. Cilliers, M. Gouws, D.M. Naicker, K. Olivier, "Hardware in the loop radar environment simulation on wideband DRFM platforms," IET radar conference 2012.
4. H.J. de Wind, J.E. Cilliers, P.L. Herselman, "DataWare: Sea Clutter and Small Boat Radar Reflectivity Databases [Best of the Web]," IEEE Signal Processing Magazine, March 2010, pp. 145-148.

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