

Simulating SAR images clutter with a sum of scatterers

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THE FRENCH AEROSPACE LAB

1. Introduction

- What do we want to simulate
- How do we want to simulate it
- How do we validate the simulation

2. Diversity from the modulus distribution

3. Diversity from the location

4. Diversity from altitude

5. Conclusion

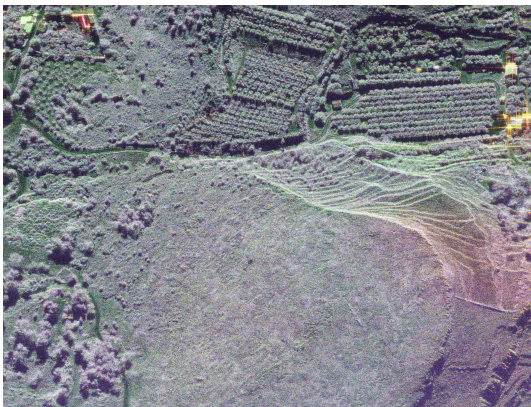
Example 1



Salon de Provence, SETHI, ONERA

- Fields with oriented structure
- Small woods and trees

Example 2



Salon de Provence, SETHI, ONERA

- Orchards
- Grass
- Altitude effects

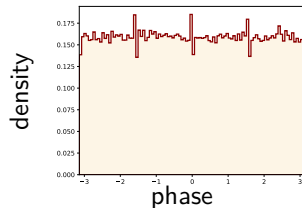
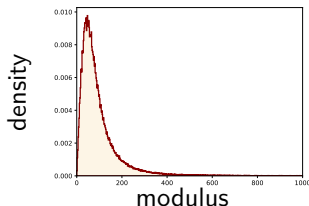
Parameters we want to retrieve

- Mean Power or mean σ_0



Toulon, TerraSAR-X, LAN3628

- Distribution of power and phase



- Texture or pattern → pixel combined 2D-distribution

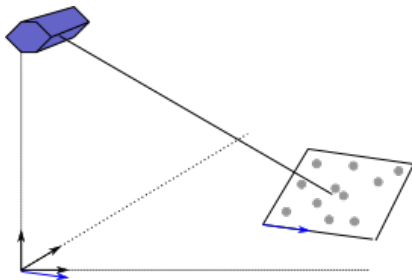
Coherent sum of scatterers

N_s scatterers defined by :

- A position (x, y, z)
- A complexe amplitude $re^{i\varphi}$
- A phase due to their distance to the sensor

A sensor :

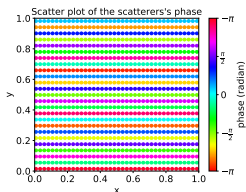
- Height $H = 514\text{km}$
- Incidence angle $\theta = 34$
- $f = 9.65\text{ GHz}$, $\lambda = 0.031\text{ m}$
- Orientation angle θ_s



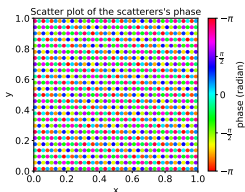
$$P = \rho e^{i\phi} = \frac{1}{\sqrt{N_s}} \sum_{n=1}^{N_s} r_n e^{i\varphi_n}$$

Impact of the orientation θ_s

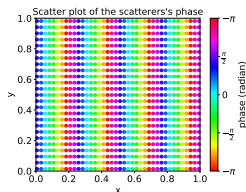
90 degrees



126 degrees



180 degrees



Changing the orientation angle changes the wavefront direction

Fully developed Speckle

A sum of a large amount of scatterers in a resolution cell which :

- amplitude r and phase φ are statistically independent
- phase φ is equi-distributed on an 2π interval.

result is a complex circular Gaussian distribution (Goodman, 1976).

$$P = \rho e^{i\phi} \sim \frac{1}{\pi 2\sigma_r^2} e^{\frac{PP^*}{2\sigma_r^2}}$$

σ_r is the second moment of the scatterers modulus distributions.

- Pixel phase is uniformly distributed on a 2π -interval
- Pixel modulus is Rayleigh-distributed

Quality indicators

In the case of fully developed speckle :

Indicators	Formula	Value	
c_v	$\frac{\sigma}{\mu}$	$\sqrt{\frac{4-\pi}{\pi}}$ ≈ 0.522723	
$\tilde{\kappa}_2$	$\tilde{m}_2 - \tilde{m}_1^2$	$\frac{1}{4}\Psi(1, 1)$ ≈ 0.411234	(Nicolas, 2002)
$\tilde{\kappa}_3$	$\tilde{m}_3 - 3\tilde{m}_1\tilde{m}_2 + 2\tilde{m}_1^3$	$\frac{1}{8}\Psi(2, 1)$ ≈ -0.300514	(Nicolas, 2002)
R	$E[e^{i\phi}]$	0	(Mardia & Jupp, 1999)

Question

How many scatterers do we need to get fully developed speckle depending on :

- Modulus distribution
- Position of the scatterers

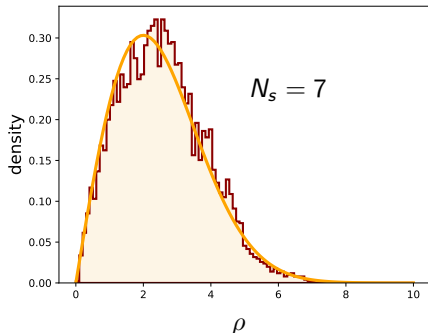
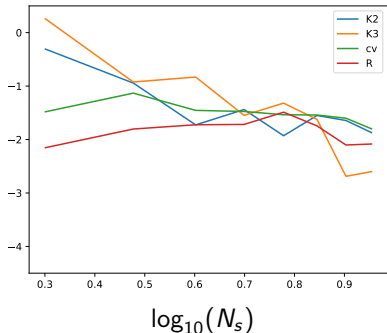
Plan

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4. Diversity from altitude
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Set up of the experiment

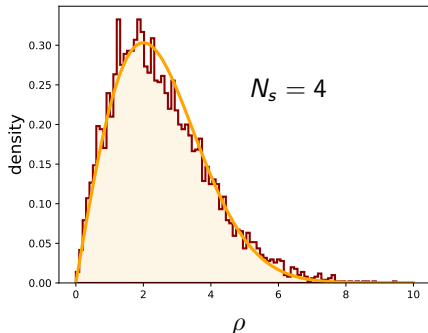
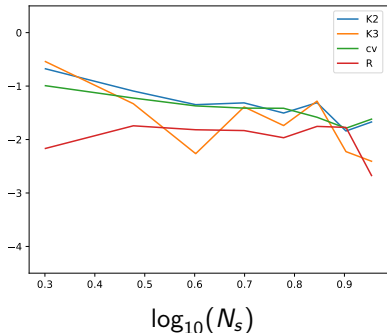
- Phase ϕ uniformly distributed on a 2π interval
- x and y uniformly distributed in the resolution cell
- $z = 0$
- Modulus ρ
 - ① Constant, with a value of $\sqrt{2}\sigma_r$
 - ② Gaussian, following $|\mathcal{N}(0, \sqrt{2}\sigma_r)|$
 - ③ Uniform, on a $[0, \sqrt{6}\sigma_r]$ interval
- Increasing the number of scatterers N_s

Constant modulus



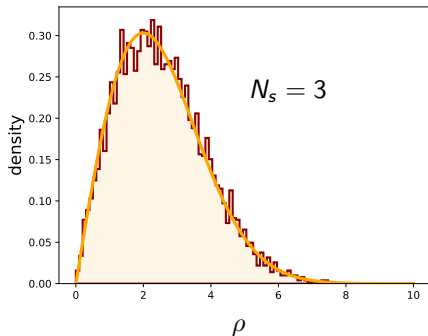
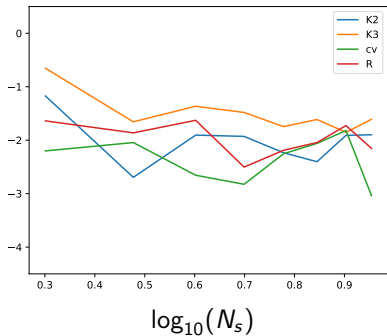
- Phase is uniformly distributed on the 2π -interval
- For N_s larger than 7, the modulus has a Rayleigh distribution

Gaussian modulus



- Phase is uniformly distributed on the 2π -interval
- For N_s larger than 4, the modulus has a Rayleigh distribution

Uniform modulus



- Phase is uniformly distributed on the 2π -interval
- For N_s larger than 3, the modulus has a Rayleigh distribution

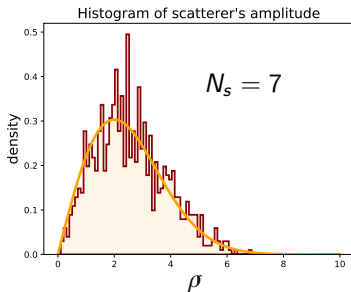
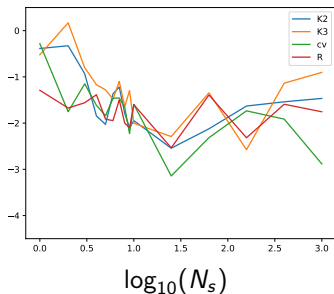
→ When the scatterers phase is uniformly distributed on the 2π -interval, diversity on the scatterers modulus decrease the number of scatterers needed in a resolution cell

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Set up of the experiment

- Phase ϕ of the scatterers is equal to 0
- Modulus ρ of the scatterers is constant
- $z = 0$
- x and y :
 - ① Uniformly distributed in the resolution cell
 - ② Distributed on a sparse grid
- Increasing the number of scatterers N_s
- Changing the orientation θ_s of the wavefront toward the resolution cell

Uniformly distributed x and y 

- Result similar to the phase randomly distributed on a 2π -interval.
 - There is $N_\varphi = 36$ phase cycles projected onto the resolution cell
- The scatterers sample uniformly the wavefront

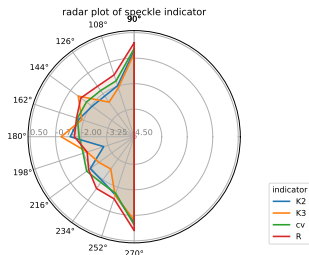
Target distributed on a grid

- The grid is sampling the wavefront
- The orientation angle θ_s influences the sampling

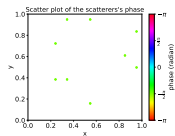
Full grid: the number of nodes is N_s

- Their is no randomness

Sparse grid: $N_s = 9$, 90 nodes on the grid

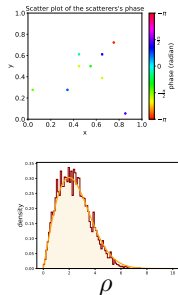


$\theta_s = 270$



All the scatterers
have the same
phase

$\theta_s = 126$



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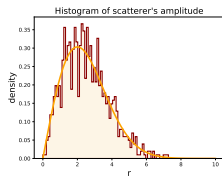
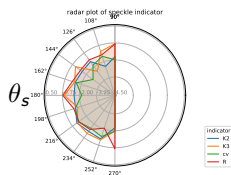
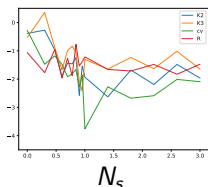
Set up of the experiment

- Phase ϕ of the scatterers is equal to 0
- Modulus ρ of the scatterers is constant
- x and y are distributed on a regular full grid
- z Uniformly distributed between $[-z_{\max}, z_{\max}]$
- Increasing the number of scatterers N_s
- Changing the orientation θ_s of the wavefront toward the resolution cell

Random scatterers height

At constant location, $z \in [-2, 2]cm$ to get $\varphi \in [-\pi, \pi]$.

On a regular grid, the position (x, y) also sample the wavefront.
 $z \in [-1, 1]cm$ can result in a fully developed speckle for some grid orientation.



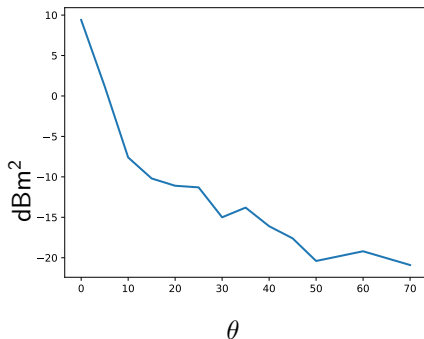
$$\theta_s = 126, N_s = 9$$

Seamless heightmap

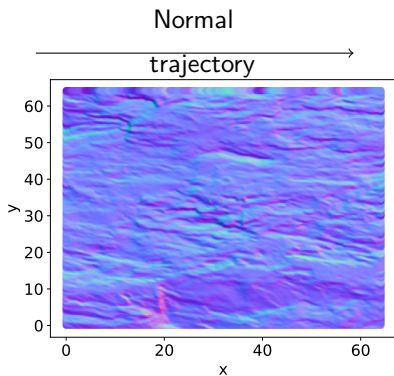
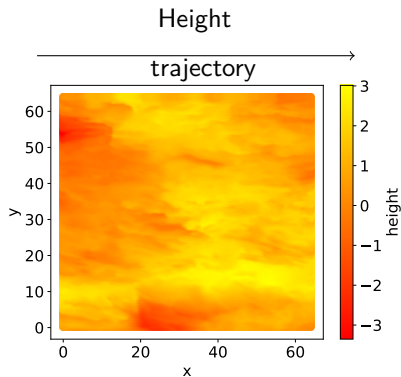
Set up :

- Modulus ρ given by a σ_0 curve (given the local incidence)
- Height z given by a seamless heightmap
- x and y resolution is 25cm
- Scatterers summed in the SAR grid

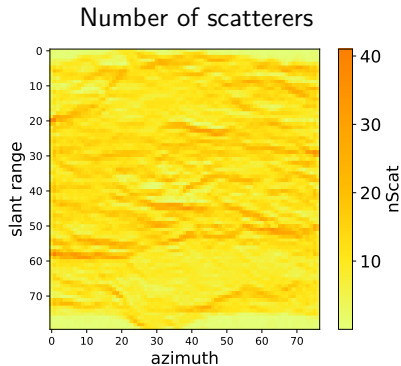
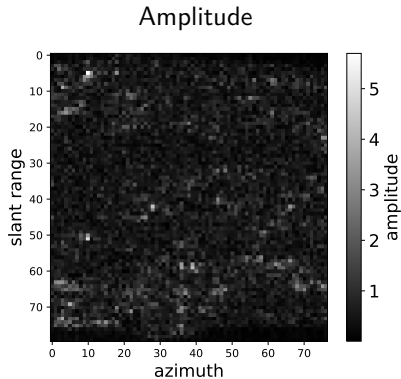
σ_0 curve "forage crop"



The seamless heightmap

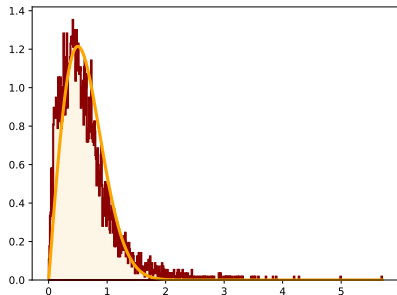


The seamless heightmap

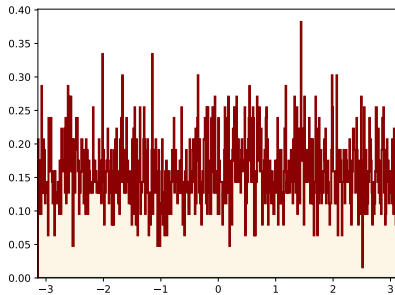


The seamless heightmap

Amplitude histogram



Phase histogram



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Diversity of the phase is key

- For a phase uniformly distributed on a 2π -interval, very few scatterers can lead to a fully developed speckle
- Increasing the variability of the modulus decreases the number of scatterers needed
- The uniform distribution of the phase can arise :
 - From a random (x, y) position
 - From a random altitude z
- ▲ If the phase of the scatterers is only due to their distance to the sensor, a (x, y) position given by a grid can lead to a unique value for the phase
- ▲ Introducing an angle θ_s between the sensor trajectory and the vector of the grid can help to retrieve phase diversity
- ◆ A textured heightmap is a mean to lead to a textured ground clutter

Bibliography I

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