Radar model

In this assignment you will implement and use a simple radar model. The model includes:

- A rough surface scattering component using the small perturbation model. Surface scattering is therefore governed by roughness spectrum and by the dielectric constant, which in turn depends on soil structure and soil moisture content.
- Scattering and attenuation due to a vegetation canopy which we model using a simplistic but useful Water Cloud Model (WCM) following Baghadi *et.al.*.
- Speckle: we are going to model the complex valued received signal as circular Gaussian random variables such that the expected value (or sample average) of the intensity is the expected NRCS.
- System noise: we will add thermal noise to our complex valued *single-look* pixels.
- Estimation of the dual-pol covariance matrix through sample averaging.

We will assume a Sentinel-1-like C-band SAR system.

Parameter	**Value**	**Notes**
	Radar	
f_0	5.4e9 Hz (5.4 GHz)	C-band
Polarization	VV, HV	V transmit and dual-pol receive
Ground range res.	5 m	Sentinel-1 IW mode parameters
Azimuth resolution	20 m	
Incidence angle	31 to 45 degree	
NESZ	-26 dB	Assumed constant, in reality it depends on angle of incidicence
Sampling	Equal to resolution	To simplify, in reality data is oversampled
	Surface	
Roughness spectrum	Gaussian	
σ_h	0.015 m	Default value
Temperature	10 C	
Sand fraction	0.51	
Clay fraction	0.14	
Bulk density	1.54 g / cm^3	
	Vegetation	
NDVI	0.1 to 0.8	

1. Considering bare soil (no canopy) adjust the autocorrelation length (*l*) of the roughness spectrum in order to have $\sigma_{0,VV}$= -10 dB (0.1 in linear units) for an angle of incidence of 40^o, and a volumetric moisture fraction $m_v = 0.2$. To illustrate the impact of l make a plot showing how the NRCS depends on the it L-, C- and X-band. Discuss the results.
2. With the adjusted *l*, make a figure showing the VV NRCS for a bare soil as a function of incidedence angle for angles of incidence of 32^0 and 40^o.

3. Adding the WCM model, i.e. combining the canopy model in Baghadi *et.al.* with our surface scattering component, make your own version of Figure 5 in the paper, i.e. compute the NRCS for VH and VV polarization as a function of NDVI for angles of incidence of 32^0 and 40^o. Repeat this for values of m_v of 0.1 and 0.25. Discuss the results addressing:
    a. How de sensitivity of the total NRCS to soil moisture depends on the NDVI.
    b. How the different contributions to the NRCS depend on the angle of incidence.

Now we will model speckle. To do that we will simulate a radar image with a chess-board pattern. Let us assume a small area, for example 1x1 km^2 (how many pixels do you have in range and in azimuth), with the scene characteristics constant in squares of 100x100 m^2. You can assume that the observation geometry (angle of incidence) is constant over the 1x1 km^2 area. Each pixel can be modeled by the product of a circular Gaussian complex random variable. For example, the following lines

```
nrcs = 0.1
slc = np.sqrt(nrcs/2) * (np.random.randn(50,200) + 1j*np.random.randn(50,200))
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generate simulated random speckle with a mean intensity of 0.1.

4. Taking constant parameters for the entire scene compute and represent the histogram of the amplitude ($|\mathrm{slc}|$) and of the intensity ($|\mathrm{slc}|^2$). Check that the histograms correspond to a Rayleigh and exponential distribution, respectively. Calculate the mean value and the standard deviation in both cases.

Now we are going to "multilook": we will compute the local average over a square region. For example, to obtain to a 20x20 m^2 product we would in this case average 4 samples (4 looks) in the range dimension. When we multilook go for second order statistics; in other words, we average the square of the amplitude, not the amplitude itself, and certainly not the complex valued SLC.

5. Generate multilooked products for 4 looks (a 20x20 m^2) 16 looks (40x40 m^2) and 100 looks (100x100 m^2) and compute the corresponding intensity of histograms and corresponding means and standard deviations. At what point do the histograms look like a Gaussian distribution?
6. Generate a checkboard pattern where the "white" squares have an NDVI of 0.5 (for example) and the "black" squares correspond to bare soil. Represent the resulting intensity, in dB, with and without multilooking (use the 16 looks option). Do this both for VV and HH polarization. You may need to adjust the dynamic range of the figure (because $\log_{10} 0 = -\infty$).

To round off the assignment we will add thermal noise. You can model noise in the same way as the "slc" variable, but with the intensity that corresponds to the NESZ. Once you have your noise realization you can add it to your SLC.

7. Redo the checkboard figures with the noise added and discuss what you see.

8. With our model, in the VH channel we only have the contribution of the vegetation (because for the small perturbation model, $\sigma_{0,VH} = 0$). Determine the NDVI value for which the SNR becomes 1.