Handout #28

GP265 / EE355

Some scattering issues

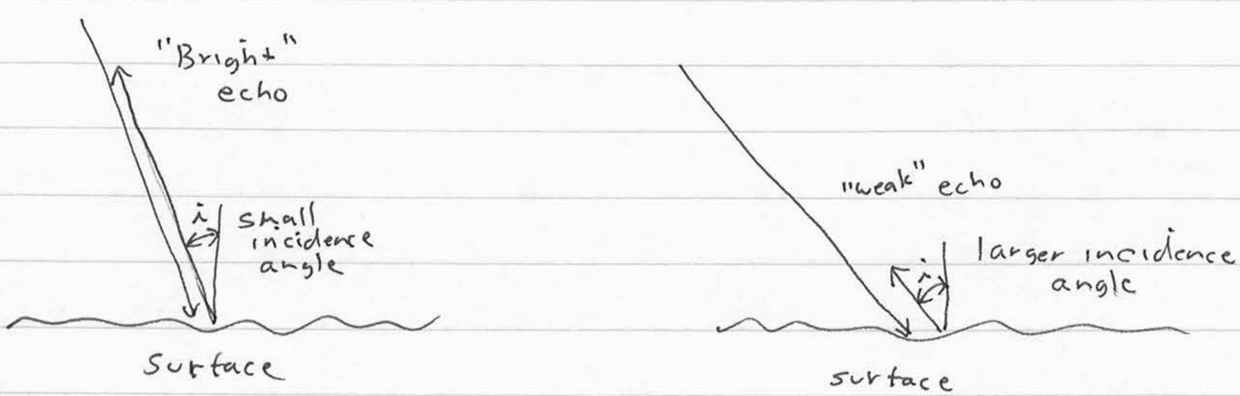
Now that we have learned to process the SAR data, it is time to begin analysis and interpretation of those data in terms of physical characteristics of the surface. While we won't spend a great deal of time on scattering and interaction topics, we will want a basic intuitive feel for the processes involved so we can understand our image data.

Scattering mechanisms

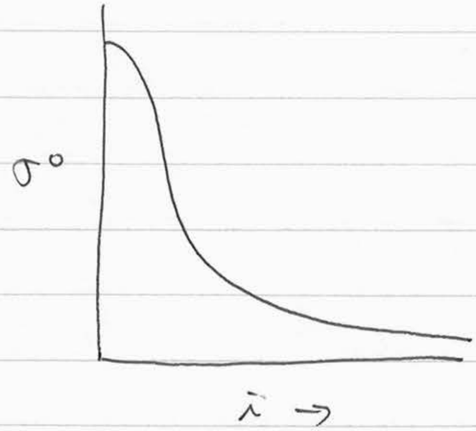
We have already expressed "brightness" in a radar image in terms of σ^0, the normalized cross-section of a surface. Since σ^0 is proportional to the echo power in the radar equation, it embodies properties of the scattering surface itself and of the imaging geometry.

Decoupling the effects of geometry and surface parameters may be done by viewing the same surface at different incidence angles. But it is required if we want to interpret the apparent brightness in the images.

Consider viewing the same surface from two different angles:



If we view the scattering process as letting more energy escape in the near forward direction than near backward, we can picture surfaces as being brighter at near-normal incidence. In fact if we plot a typical curve of σ^0 vs i, we get something like

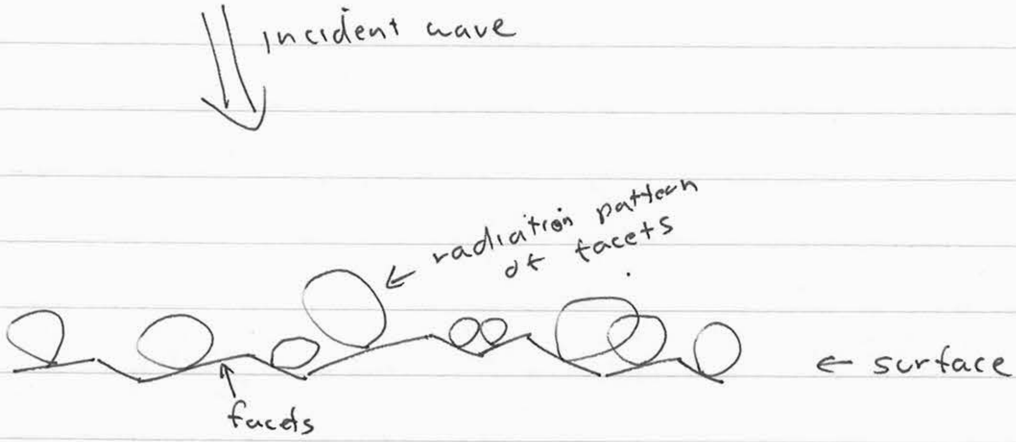


We have discussed already how the modulation of the local incidence angle in a radar image, coupled with a σ^0 curve like the one above, gives rise to the bright and dim areas associated with topography.

Now, the σ^0 response plotted above can be better understood if we try to relate its shape to surface parameters. It turns out to be easier to do this if we adopt simplified scattering models applicable to different regimes of i. This is equivalent to examining different scattering mechanisms for the different incidence angles.

<u>Near-normal scattering</u> - facet models

Consider first scattering for very small angles of incidence i. Then we can model the interaction as a series of mirrors, or facets, reflecting the incident wave:



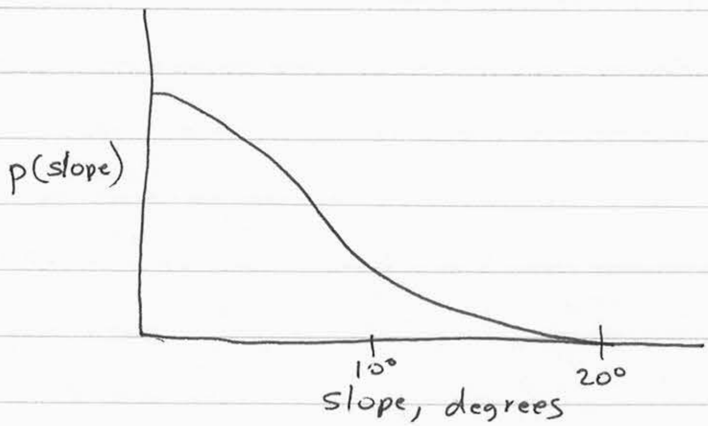
Each facet has an "equivalent radiation pattern" related to an equivalent antenna which reradiates incident energy. The return from each facet is greatest when illuminated normally, and fall off typically as a dipole (cosine) radiation pattern.

We can simplify matters still more by first assuming all facets are the same length, thus the reradiation patterns are the same size but of varying orientations. If all the returns add incoherently, which is the case if the facets are separated in range by a wavelength or more, Then the total backscattered power is simply related to the fraction of facets oriented at the radar, integrated over a range of angles equal to the width of each pattern.

If we have multiple facet sizes, we need simply to integrate over the distribution of sizes.

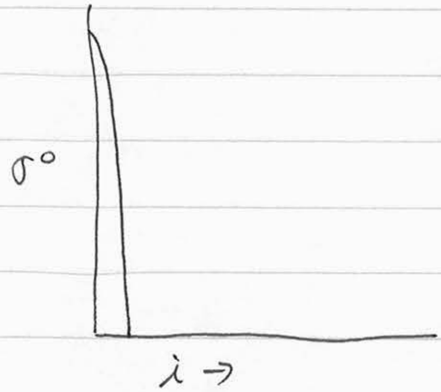
Hence the probability distribution of facets is the key parameter determining σ° for this model. A little thought shows this distribution is expressed as the probability distribution of surface slopes.

A typical slope distribution might be:

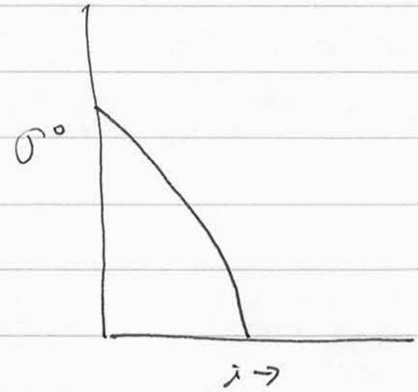


This surface, with a standard deviation of slopes ~10° is about as rough a surface as you will find. For most surfaces the angle of repose (slope) doesn't exceed about 20°.

Now, $\sigma°$ will be related to a 2-D integral over slopes, hence we can ~~comple~~ compare $\sigma°$ by computing the average power over the range of slopes for a given surface. For very smooth surfaces, such as water, the probability of a slope greater than 1-2° is rare. Thus we can infer surface slope or roughness by examining the near-nadir $\sigma°$:



Smooth surface



Rough surface

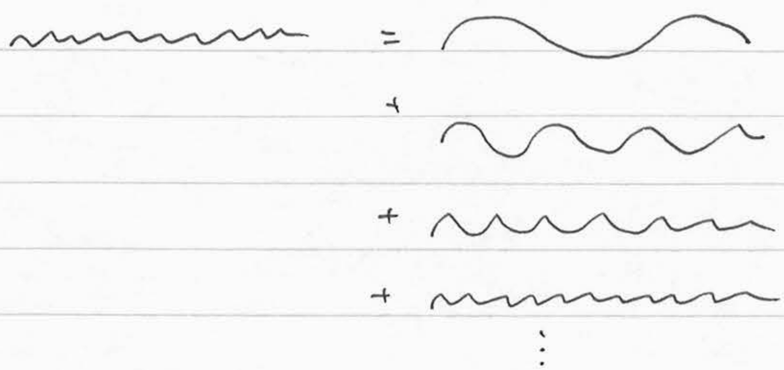
More detailed models incorporating curvature effects as well yield better approximations to the real σ°. These are called variously quasi-specular or Kirchoff scattering models and are dealt with in greater depth in EE354.

Greater Incidence Angles – Bragg scatter

The facet-type mechanism yields little energy for $i > \sim 20°$, but clearly we can image very much larger angles than this. One mechanism dominant at these angles is called Bragg scattering, and is valid for $i > \sim 20°$.

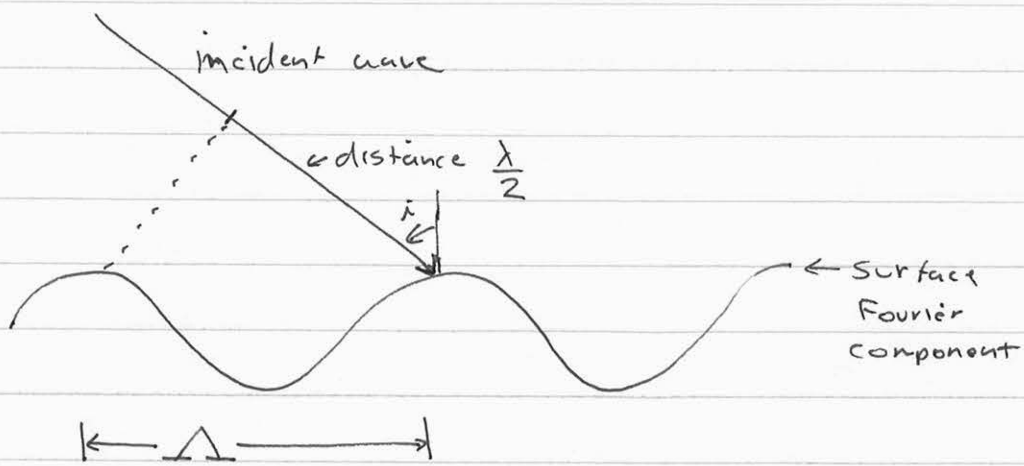
For the Bragg model, consider a surface divided into a large-scale, faceted component and a small-scale residual roughness component.

Putting the faceted part aside for the moment, consider the small-scale component alone. Break it up using Fourier decomposition:



Now, the amplitude of each of the Fourier components will be small. For the model to be easily evaluated we require the rms height of the surface to be less than about $\frac{\lambda}{8}$ in amplitude, which is why ~~we~~ we removed the large-scale facet term.

Consider the Fourier component for which the distance Δ below is equal to $\frac{\lambda}{2} \sin i$:



Note that because of the round-trip distance of λ between like parts of the surface Fourier component, energy from everywhere on the surface adds up in phase, therefore this component is "brighter" than others. This component is the only one "matched" to the wavelength of the incident radiation.

If the surface component at this frequency has higher amplitude, the radar return will increase.

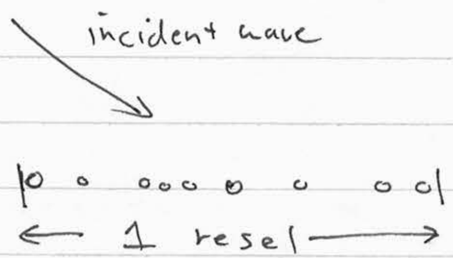
Therefore, in the Bragg model, we simply expand the surface to find the amplitude of the Fourier component resonant with our incident radiation. Eventually we could derive the following expression for σ^0 in the Bragg-dominated domain:

$$\sigma^{\circ}_{(pol)} = 8\left(\frac{2\pi}{\lambda}\right)^4 h^2 \cos^4(\theta)\ |\alpha_{pol}|\ W\left(\frac{4\pi}{\lambda}\sin\theta\right)$$

The subscript pol means that wave polarization affects the result through α_{pol}. Note that the cross-section is proportional to h^2, the rms surface height squared, and to the Fourier component of resonance $W\left(\frac{4\pi}{\lambda}\sin\theta\right)$.

Discrete scatterer model

Another model for larger incidence angles, which we'll use extensively when we consider interferometry, consists of a random distribution of discrete scatterers. Let each scatterer be an object with similar backscattering properties, and illuminate it with an incident wave:



The returns from each scatterer add coherently, but because the resel is >> than λ the phase is essentially random in the sum, and we can just add the powers to obtain σ°.

Hence extending this argument we obtain

$$\sigma^{\circ}(\theta) = \underbrace{N}_{\text{scatterers per unit ground area}} \cdot \sigma_{1\,\text{scatterer}} \cdot \underbrace{\cos\theta}_{\text{obliquity factor}} \quad \leftarrow \text{isotropic scatterers}$$

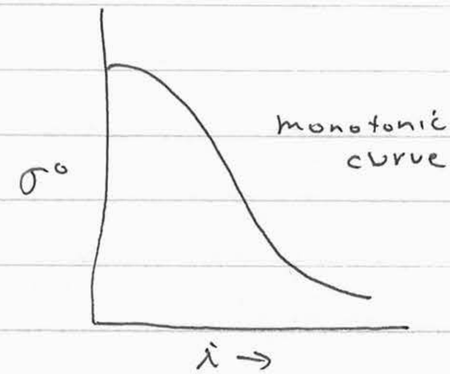
or

$$\sigma^\circ(\theta) = N \cdot \sigma_{1\,scatterer} \cdot \cos^2\theta \qquad \leftarrow \text{for } \cos(\theta) \text{ reradiation pattern}$$

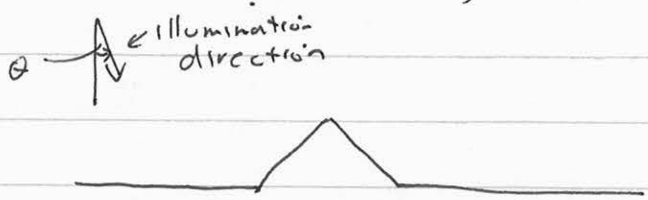
Both of these fall off more slowly than the Bragg model, which went as $\cos^4\theta$, so are applicable to even rougher surfaces than those we can model with Bragg scatter.

<u>Slope modulation and topography</u>

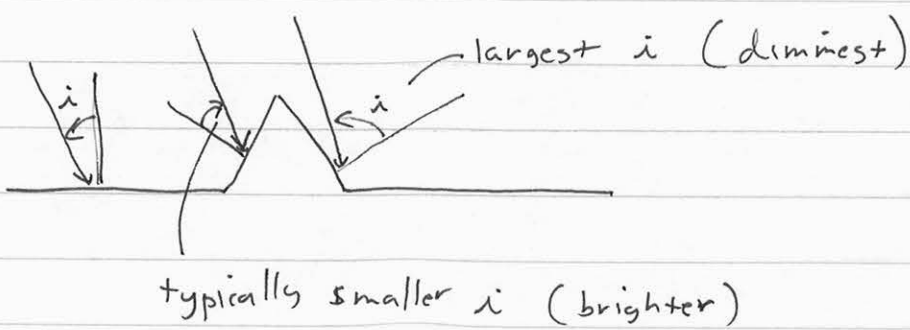
Consider our canonical σ°:



and image the following surface:

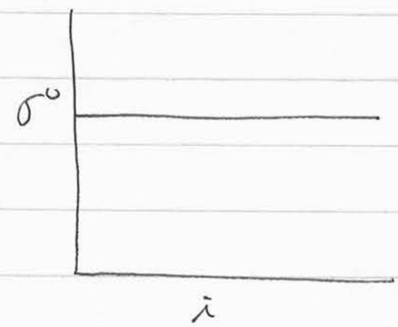


Let's determine the local incidence angles.



Thus this topographic feature would appear brighter on its near side and dimmer on its far side. This effect causes even subtle changes in topography to be visible in a radar image.

At very short wavelengths, where the surface is effectively extremely rough, σ^0 looks like



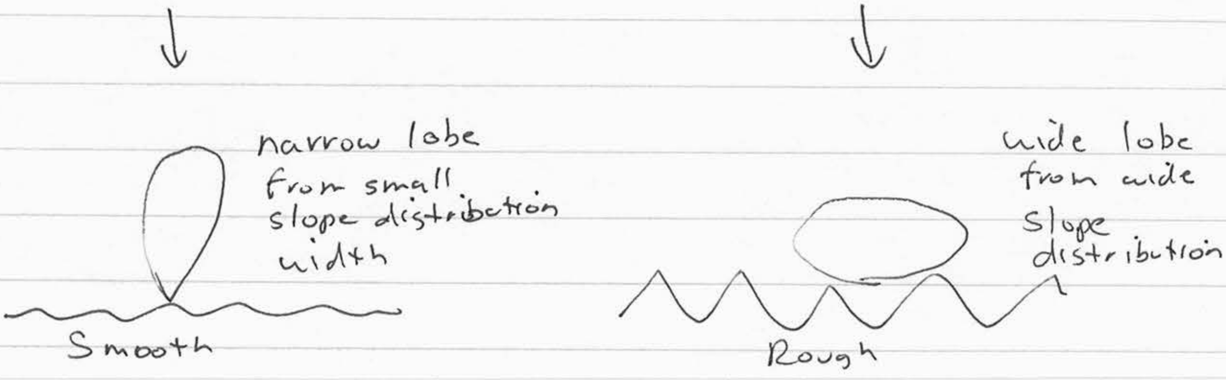
and sensitivity to topography decreases, or disappears. This happens often at optical wavelengths.

Surface roughness variations

Now we can understand two effects on radar echoes from roughness variations - increasing roughness decreases intensity from facet scattering and increases intensity from Bragg scattering?

Why is that?

Facet scatter (near normal)

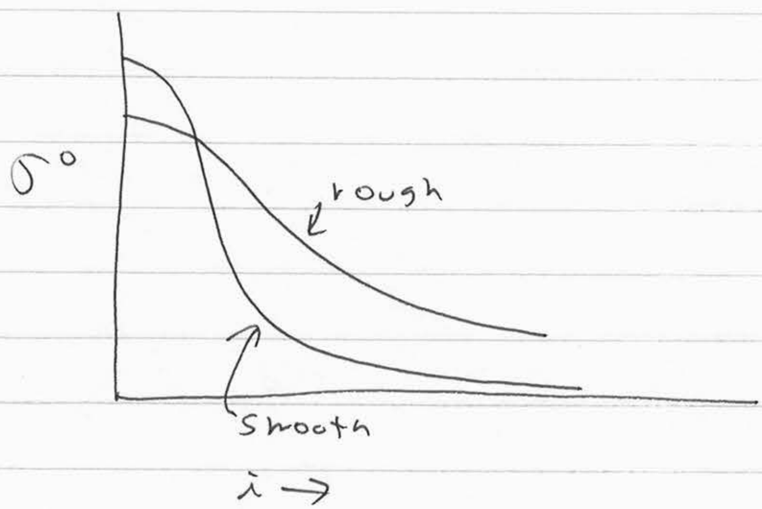


For Bragg, recall the Bragg law form:

$$\sigma^0_{pol} = 8\left(\frac{2\pi}{\lambda}\right)^4 h^2 \cos^4\theta \, \alpha_{pol} \, W\left(\frac{4\pi}{\lambda}\sin i\right)$$

σ^0 is proportional to h^2, so increased roughness leads to increased backscatter.

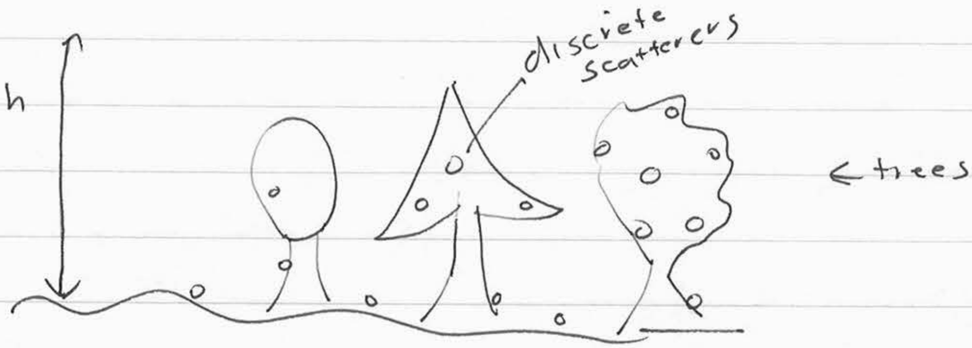
So, two surfaces might compare as follows:



Also, since topographic contrast depends on $\frac{\partial \sigma^0(\theta)}{\partial \theta}$, more shading is apparent in smoother areas than rougher areas.

<u>Vegetation</u>

Scattering from vegetation can be thought of as a form of scattering from an extremely rough surface:



These scatterers are widely distributed in a large volume, with equivalent h^2 very large. Hence we would expect little dependence on i in very dense canopies when ~~teg~~ little or no energy penetrates to the ground. The sigma-zero curve is essentially flat.

Thus, one common method to calibrate radars without having to calculate incidence angle effects is to image a dense canopy such as the Amazon rain forest.