Remote Sensing: Principles and Applications
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Lecture-48
Active Microwave Remote Sensing-Radar-Part-5

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. We are discussing the topic of active microwave remote sensing with imaging radar. In the last lectures, we got introduced to the concept of how radar image is acquired, what sort of image distortions will occur and the concept of resolution in a radar image. In this lecture, we are going to see the actual signal contained within a radar image, what characterizes it and the terrain properties that influences the reflection of objects in the radar signal

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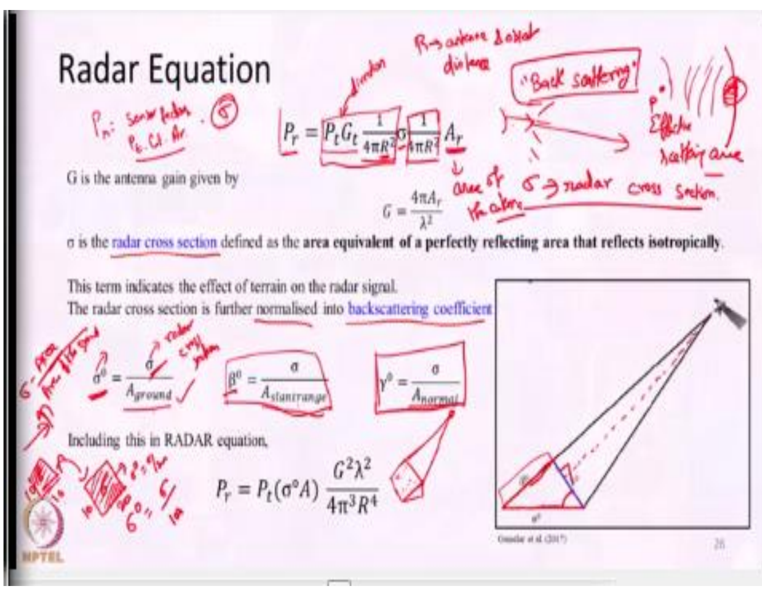

First we will get introduced to the radar equation and what is actually contained in a radar image. The concept of radar image is that it will collect the power that is being reflected back from the object. So, here the term reflection means the signal which is reflected in the same direction as that of the receiver. Because we know that radar will have an antenna, it will transmit microwave radiation towards the object and whatever is reflected towards the antenna again alone will be collected. So, whatever reflection or scattering happens in direction anything other than this antenna direction will not be collected by this particular sensor, so we call this as backscattering.

So, essentially the radar antenna measures what is known as back scattering, that is how much energy is being scattered back by the object towards the sensor is called as backscattering.

So, normally when you look at any scientific literature related to radar remote sensing, we will have this term backscattering commonly being referred to the power received by the antenna. So, the power received by the antenna depends upon the power transmitted multiplied by the gain of the antenna. So, here gain means how well the antenna is focusing the power in a given direction. So, once the power is transmitted a pulse is being released, it will start spreading in all the three dimensions, it is not going to travel in a straight line. Microwave pulses, the power is going to spread across in all the directions, we know this because of this inverse square law, whatever is the power that is transmitted it is going to spread across. So, this $1/4\pi R^2$ is to account for this spreading of power, where this R is the distance between the radar antenna and the object.

So, if P power is transmitted from an antenna towards a target, it will slowly start spreading in the entire sphere surrounding it. So, we are going to use this inverse square law function in order to calculate what is the power received by this particular object with the given area. So, now these three terms will define the power reaching the object of interest from the radar antenna. The initial power that was transmitted multiplied by the gain and accounting for the spreading loss. Now, whatever is the power reflected back will depend on the effective scattering area of the object or here we denote it as σ, where σ is known as the radar cross section. So, for radar cross section, think it in terms of like reflectance. So, some amount of power is reflected back by this particular object and it has to again travel back, after reflection it will start spreading again, from this particular small area to all over again.

So, this particular term $1/4\pi R^2$ and A_r is the area of the antenna that is receiving the signal. So, if you divide this particular equation into different components like sensor and object characteristics, we can know that, the power received depends on some sensor factors or sensor characteristics, that is the term P_t, G_t, A_r, area of antenna are all sensor factors. The σ what we referred as the radar cross section actually defines the property of the object on the earth surface that controls this power that is reaching the sensor. So, essentially, that single particular term σ, the radar cross section will influence how much power will be returned back to the radar antenna and that is entirely controlled by the object of interest itself, rest all the factors are all system properties.

So, the power received and the other system properties are all fixed, once the system is launched. It is fixed means, when an image is acquired the σ term is the only variable in the equation that changes every time, the radar cross section term. Also the distance which is a natural phenomenon is always going to vary. So, the major factor that controls the signal received in the radar image, is radar cross section. Let us say there is some object. Now, radar power is falling on it and the object is sending back certain amount of that particular incident energy towards the radar antenna. In order to calculate the power scattered back by the object of interest, we take some reference. That reference is like a perfect isotropic reflector which means a polished spherical metallic surface, which has good amount of scattering in the microwave wavelength and it will scatter the micro wavelengths equally in all the directions**,** like a spherical metallic surface you can think of. So, that is taken as a reference and whatever be the microwave power that is falling over it, that power will be scattered equally in all directions by that particular object.

Now let us say, we have some object of interest, that is scattering the energy back towards the antenna, any feature, cropland, water body, building, whatever. Let the power that was scattered back towards the antenna be X. So, now, what we have to estimate the area of this isotropic reflector that should be there in order to reflect back or scatter back the same power X towards the antenna under identical illumination conditions. I repeat it again for sake of clarity. Let there be any object of interest on earth surface, let us say it is scattering some power X towards the antenna in response to the incoming microwave signals. Radar cross section here means, the area of a perfect isotropic scattering object. So, the surface area of the object that is required in order to scatter back the same amount of power X under identical illumination conditions by the microwave. So, here we are not calculating the reflectance of object, but here we are trying to calculate the area of the isotropic reflector that is required to produce the same amount of power that is been reflected back.

It may appear little bit confusing in the first go, but concept wise it is very simple. Let us say there is a very good reflector in the microwave, let us take an example of a very healthy crop plant or a vegetation or a standing water. So, these objects will produce a very bright response and they will appear very bright in radar images. They will send back almost most of the energy that was transmitted from the radar, they have very high backscattering towards the radar. So, in order to produce such a bright backscattering towards the antenna, that particular object should be replaced by an isotropic reflector with a bigger area. Let us say there is some other object which is a very poor backscatter, like a calm still water body, the back scattering will be really poor towards the antenna.

Under that circumstance the area of the isotropic reflector to produce the same backscattering will be smaller. So, essentially based on the backscattering capacity of the actual terrain features, we can calculate the surface area of the perfect isotropic reflector that will be needed to produce the same amount of power. So, this is known as radar cross section. Normally in optical remote sensing, for reflectance we will calculate the ratio, ratio of the energy that was reflected back to the energy that was incident. Here we are not doing that, here we are trying to do some sort of hypothetical calculations like where we try to calculate the area of the perfect isotropic reflector that is required to produce the same amount of backscattering produced by any natural feature.

Higher the backscattering capacity of this natural feature, larger will be the area of this particular isotropic reflector that will be required hence the radar backscattering will be larger. If the object has a lower backscattering capacity, then even a small area of this isotropic reflector can produce the same backscattering and hence the radar cross section will be smaller. So, the radar cross section essentially tells the backscattering capacity of the object.

So, here we told the radar cross section essentially determines the power that is reaching back the sensor. But this radar cross section has to be normalized with respect to something. That means normally a single pixel will have many numbers of features, if you take a 10 m by 10 m pixel, a large number of features will be present. So, there can be many objects, so we will get a combined radar cross section. But in order to normalize this, in order to bring it to some sort of standard, we will convert that to what is known as a radar backscattering coefficient. So, this is denoted here as σ^o , the radar cross section is kind of normalized further to backscattering coefficient. Now, it is like a ratio where the numerator has the radar cross section and the denominator have the area on the ground that produces or that requires this much radar cross section. This σ is nothing but the area of the perfect isotropic backscatter, that is needed in order to produce the same backscattering received at the antenna under identical illumination conditions, divided by area of the ground that actually produced that radar, the radar cross section.

So, here we are now dividing and now we are converting to a ratio**.** This is the area of the object or this is the area of the isotropic reflector that is required. Once we calculate it, we normalize that with respect to the area of the ground that produced or that requires that much radar cross section. This is needed, because radar pixel size is not a constant**.** We have seen that the pixel size of radar images will vary across the range direction and azimuth direction in case of real aperture radars. If that is the scenario as the pixel size changes, some pixel may have large number of objects, some pixel may have but sub pixel size itself may be small dimensions, it may contain very few objects that has poor backscattering capacity, all these things will happen.

And the radar cross section σ itself will depend on the actual ground area that is covered by the radar pulse. In order to avoid this, we convert this radar cross section to radar backscattering coefficient. So, that the power received in the antenna will be normalized to per unit meter of ground area. Say for a pixel, the radar cross section per unit meter of ground area is what we will calculate. Let us say there is a pixel size 10 m by 10 m. So, whatever be the radar cross section, we will divide this by 100 m^2 in order to calculate this backscattering coefficient. So, essentially this is what we will calculate in radar image preprocessing. So, whenever a radar image comes, we will do some sort of preprocessing steps before we use it for further applications.

So, one of the important steps is to convert the slant range distance to ground range distance, remove the distortions using terrain correction procedure, after that we will convert everything to radar backscattering coefficient. So, the backscattering coefficient will tell, at each pixel what is the radar cross section required per unit meter square of area. Let us take two examples, one pixel 10 m by 10 m, another pixel 10 m by 20 m. It is natural that radar resolution will vary across the image in both the range direction and azimuth direction. If that is the case let us say both the pixels had same radar cross section and in this 10 m by 10 m pixel, there are lot of bright objects. Whereas, this 10 m by 20 m pixel had a smaller number of objects. Let us assume both of them has the same radar cross section, but the same radar cross section has been produced by these pixels, one of the major factors that produced is the larger dimension of this pixel. Though the dimension be uniform between these 2 pixels, the radar cross section might have been different. In order to normalize that we convert this, so σ^o of this pixel will be σ by 100 meters, whereas σ^o of this pixel will be whatever the σ divided by 200 meters.

So, essentially using the area on the ground we will normalize the radar cross section for this variation in pixel size. So, we calculate the σ^o and we can define the area in multiple ways. Normally, the general convention that we use is the actual ground area of the pixel that is the actual horizontal dimensions of the ground in the X direction and Y direction, calculate area out of it and use it, that we call it as σ^o. We can also calculate the area of the ground in different directions. Say for example, a schematic is given here, if we use the actual horizontal ground area in order to normalize the radar cross section, we get σ^o. Now, if we use the slant range area itself, that is in the slant range let us say this is the antenna; this is the ground, so the beam will be spreading like this and collect all the distance information and power information.

So, whatever each pixel here, it will have an area projected in the slant range direction. So, if we use the area of the ground which is used to define the pixel in the slant range direction itself for normalizing the radar cross section, we call it as β^o. On the other hand, if we project this ground area in a direction that is normal to the radar beam or the radar antenna, then, if we use that area to normalize this radar cross section, we call it as γ^o. So, the radar backscattering coefficient can be defined in 3 ways or the area itself can be defined in 3 ways. They are the actual ground area, the area of the pixel that produced the σ and the radar cross section in the slant range or the area of the ground projected in a direction normal to the radar antenna.

But the general convention and the most often used factor is σ^o, radar cross section σ divided by the horizontal ground area. So, obtaining the σ^o for each pixel will be one of the important steps in radar data processing. Once we get this σ^o, we can use it for different applications. So, the σ^o essentially influences the terrain features and the power that is reaching the radar antenna. So, higher the backscattering coefficient σ^o, the pixel will appear brighter and lower the σ^o, the object would not have backscattered high amount of power, it would have backscattered only very less amount of power. So, the σ^o essentially tells us the characteristics of the object and its ability to backscatter microwave signal. Now, we are going to discuss what are all the factors of the terrain features that will influence this σ^o. When we discussed the optical remote sensing, visible, NIR remote sensing, we discussed what factors of vegetation controls its spectral reflectance curve, what factors of water controls its spectral reflectance curve and so on. Similarly, we will touch upon briefly how different features exhibit this or how different factors of the features on earth surface control this σ^o. So, basically from the radar equation, we have inferred that the power reaching the sensor depends both on sensor characteristics and the object characteristics which means the feature present on the earth surface. Some of the important sensor characteristics that control this power reaching the sensor are the frequency in which the microwave signal is transmitted.

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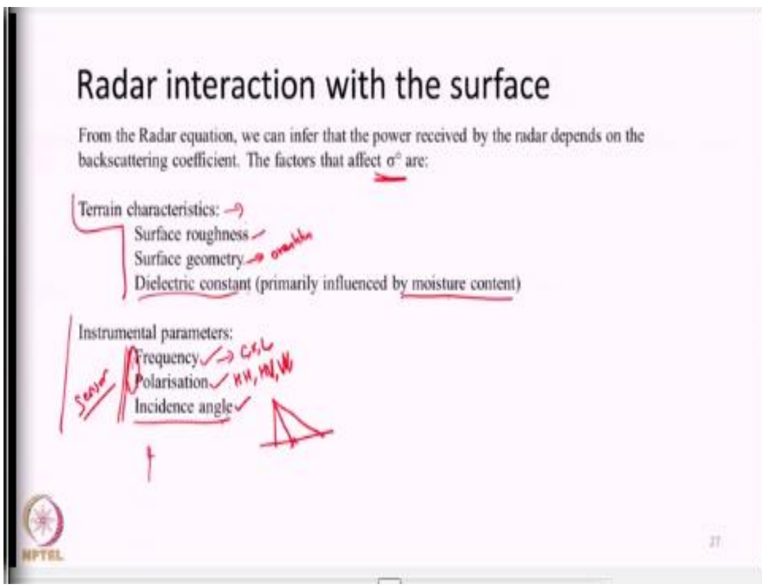

The polarization of the signal that is transmitted and received and the incidence angle are the three really important factors, from the sensor side that will control the power that is received back by the sensor. So, frequency means here means whether it the C band, X band radar, L band radar and so on. Polarization means whether it is transmitting in horizontal and receiving in horizontal or HV or VV. An incidence angle which is, whether the object is closer to the radar antenna, whether it is near range or whether it is in far range and so on. So, these are all the instrumental parameters, but as I said before except this incidence angle once the system is launched, these two are fixed. The incidence angle is going to vary based on whether the object is present in near range or far range. But what we are really interested upon is to understand, what are all the terrain characteristics that influence this σ^o. The important terrain characteristic that influences microwave backscattering is the surface roughness that is how rough or how smooth the surface is. Surface geometry, basically deals with the orientation of the surface itself, different features that are present on the surface and the dielectric constant of the surface, primarily influenced by its moisture content. So, these 3 factors are the key controlling factors from the object side or the terrain side that will control the microwave backscattering towards radar antenna. So, essentially by looking at the σ^o value, we may get some information about any of these, either surface roughness property or dielectric constant of the surface and so on.

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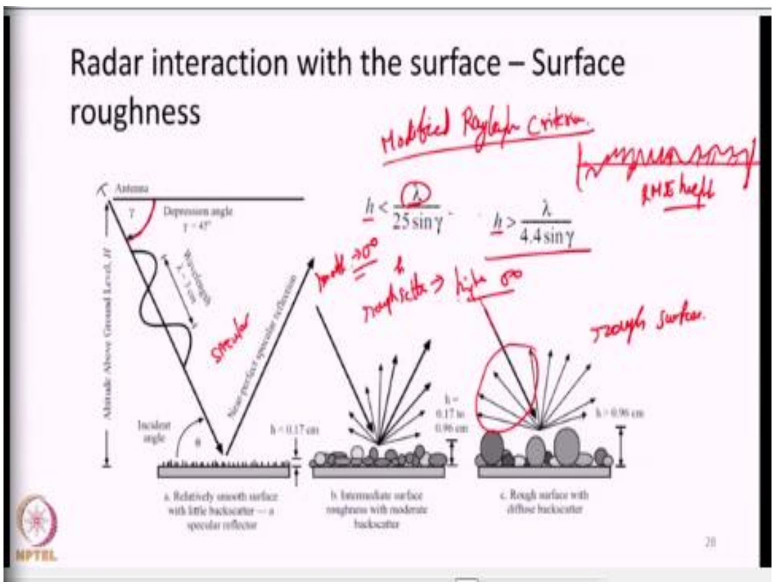

So, first we are going to discuss the importance of surface roughness in the radar backscattering. Actually we have seen this in the earlier classes also, when we discussed the interaction of electromagnetic radiation with the terrain. The surface roughness, whether it will appear smooth or rough, it depends on the wavelength that is incident on the surface and also the look angle that is the geometry between the sensor and the object itself. Here in radar also the same case, the surface roughness plays a major role, that is whenever we get signals from the radar, surface roughness will have a larger influence, there can be drastic variations also.

In previous lectures, we have defined what is known as a modified Rayleigh criterion, please recall them. Let us say this is a soil surface. So, this is the mean height of this particular bounding area in which I am interested upon, so this is the mean height of the area. So, the variation of the surface is measured with respect to mean height. If we can calculate the deviation or the difference, we can land up what is known as the RMSE height. If this RMSE height is less than $\lambda/25\sin\gamma$. The surface will be smooth for this particular wavelength and will act like a specular reflector. If a surface is smooth, it will act as a specular reflector, if a surface is rough, that is the RMSE height, h greater than $\lambda/4.4\sin\gamma$, it will act as a rough surface or if the RMSE height is varying between these 2 limits the surface will act like an intermediate. So, what exactly will happen? For a smooth surface the reflection will be specular and it will be moving away from the radar antenna. Let us take still calm which is a very good example for a specular reflector. Say this is like the standing water column let us assume, microwave signal is incident on this particular water column. Since it is very smooth, radar energy will be reflected specularly.

So, most of the energy is going in a direction away from the radar antenna. So, the radar antenna which is looking for the backscattering is not going to receive any large chunk of energy, a large chunk of energy is lost in the direction opposite to that of radar antenna. So, normally specular surfaces will appear dark in microwave or radar images. If the surface is rough, let us say a dry agricultural field that is just being ploughed. So, for such surfaces, it will appear rough to the microwave wavelengths, so it will produce scattering in all directions. Normally rough surfaces act more like a diffused reflector which will reflect the energy or scatter the energy in all possible directions. When that happens, a good chunk of energy will be scattered towards the antenna itself. So, a rough surface naturally will have higher σ^o and a smooth surface will have a lower σ^o under the case of all other factors being held constant.

Say, this particular slide demonstrates that the surface roughness is a function of the wavelength and also the depression angle or incident angle. Normally depression angle and the look angle are kind of complementary to each other, so here we are using the notation of depression angle. So, a surface may appear rough to one particular wavelength say X band radar around 3 cm wavelength. Whereas that same surface itself may appear smooth to L band radar with close to 24 cm wavelength. So, let us say here the RMSE height of the surface is 0.4 cm.

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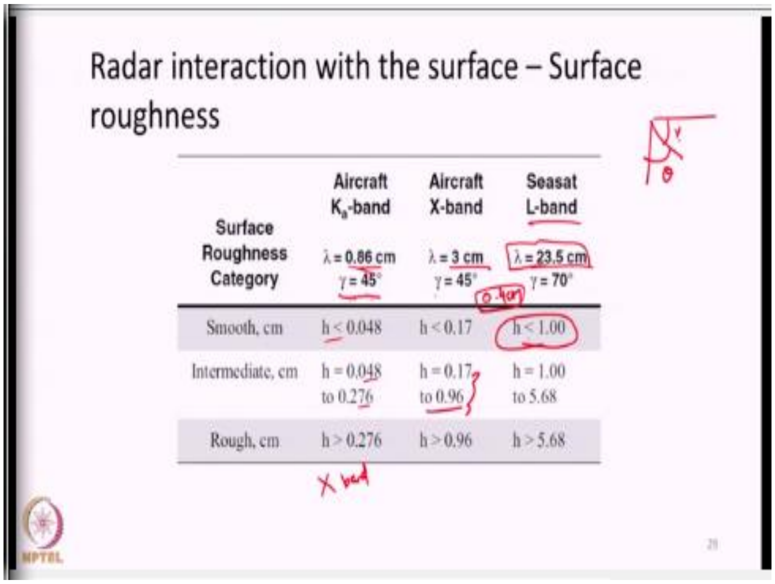

So, for the X band radar this surface will appear like a rough surface or like an intermediate surface**,** whereas, for an L band radar this will appear like a smooth surface producing difference in backscattering. So, the band in which we are looking upon, that is the wavelength in which you are looking upon and the sensor incident angle are going to play a major role in controlling the backscattering from the object. One more thing what we want to know is, this is like the general surface roughness characteristic, roughness of just the top surface, be it a bare soil, be it a dense forest where the roughness will be defined by the canopy**.**

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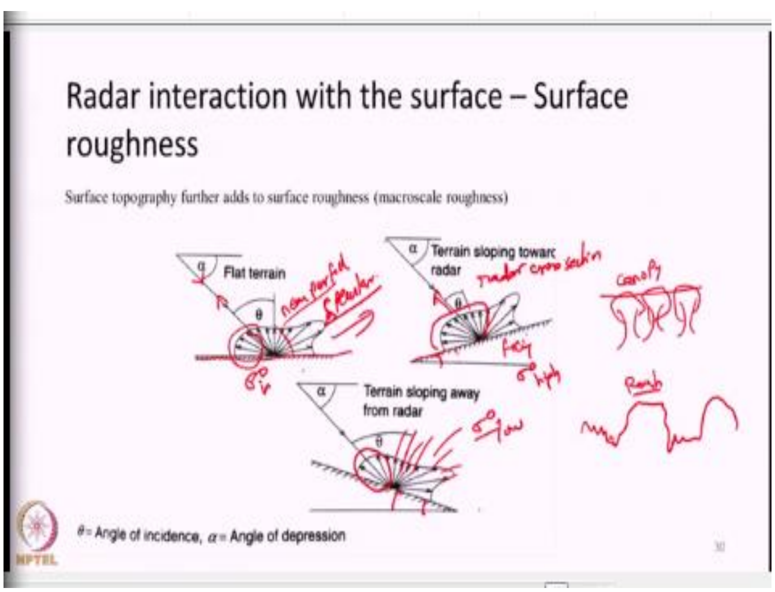

If we have a large cluster of trees, the radar signal will be encountering this tree tops what we call the canopy. And if you closely observe the canopy, the canopy cover may not be smooth, it may be something like this, each tree there can be small leaves, twigs everything may protruding out. So, this will project a kind of rough surface, so this is generally the surface roughness layer characteristics. But what about the overall orientation of this particular surface, like let us assume there is a dense forest that is present on a flat horizontal surface and exactly the same dense forest if it is placed on a sloping surface, how that will change the radar signals? That kind of schematic, we will see now.

The major share of energy is transmitted in forward direction, so we call it as near perfect specular reflector. Let us say this is present on a flat horizontal surface. So, a major fraction of energy will be reflected in the forward direction away from the radar and a smaller fraction of energy alone will be backscattered. Let us say the same object is present on a slope that is facing the radar antenna**.** Due to this topography, even though the object is reflecting a large fraction of energy in the forward direction, still a major fraction of backscattered energy is oriented towards the radar antenna itself thereby increasing the radar cross section.

So, the same near perfect specular reflector, if it is present on a slope facing the radar antenna, because of this terrain characteristic or the sloping nature, relatively higher fraction of energy will be transmitted towards radar antenna. On the other hand, if this near perfect specular reflector is present on a slope facing away from the radar antenna, the amount of energy backscatter towards radar will further decrease. The slope will be reflecting the energy further away from the radar antenna, only a smaller section of energy is going towards the radar antenna. So, not only the surface roughness influences, but the overall orientation of the surface also matters, we call it as macroscopic effect or the topographic effect.

So, the overall topographic effect where the surface roughness element is present, that will also play a major role. Say in the example that we have just seen this will have the lowest back σ^o, because large chunk of energy is transmitted away from the radar antenna. This will have an intermediate σ^o; this will have like a high σ^o relatively. So, everything is in a relative sense with respect to each one of these 3 things.

So, as a summary, in this lecture, we have discussed the factors that will influence the power that is reaching the antenna. We discussed, what radar cross section is, what radar backscattering coefficient is. And we just listed the different properties of the surface that will influence this radar backscattering coefficient. And the major factor that influences radar backscattering coefficient is surface roughness. And also we have seen how surface roughness plays a role in controlling σ^o. With this we end this lecture.

Thank you very much.