Discussions on A Phenomenon That Forest Edges Do Not Accompany Radar Shadow in L-band Airborne SAR Images

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Abstract

In the airborne SAR images obtained during the SAR-580 Experiment in Japan, we have observed that edges of pine forests have no shadow at the L band, while they accompany a clear shadow at the C and X bands. This paper discusses the reason why the forests do not accompany a shadow at the L band by considering three processes: penetration, multiple scattering among branches and trunks, and forward scattering by thick branches and trunks.

1. Introduction

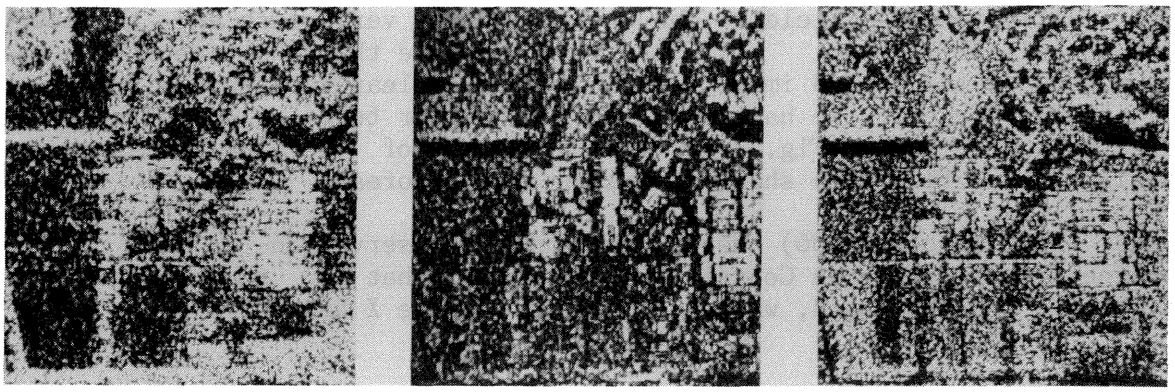
In the images obtained during an airborne synthetic-aperture radar (SAR) campaign, made in Japan in 1983, we found that edges of pine forests have no shadow at the L band, while they accompany a clear shadow at the C and X bands (Hirosawa, 1985). The campaign, named the SAR-580 Experiment, was conducted by the National Space Development Agency (NASDA) of Japan using the three bands SAR system of the Canada Centre for Remote Sensing mounted on the Convair-580 aircraft. The observation that the pine forests have no shadow at the L band seems to indicate that the trees are transparent for the L band microwave.

We have another observation concerning the penetration characteristics of trees, which measured, in 1986, a transmittance of tree canopies at the L band putting a pair of antennas, for transmitting and receiving, such that the microwave penetrated through trees obliquely (Murata, et al., 1987a). The typical attenuation through pines was from 5 to 10 dB (one way) per one or two tree-stands (Murata, et al., 1987b).

Two observations mentioned above seem to contradict each other. This paper discusses the reason why the pine forests had no shadow in the L-band SAR images by considering three processes: penetration through tree canopies, multiple scattering among branches and trunks, and forward scattering by thick branches and trunks.

2. Airborne SAR Images of Pine Forests

Fig. 1 shows the SAR images, at the L, C and X bands, of an agricultural field of the Tsukuba University. Each are a part of the large images obtained by the SAR-580 Experiment. The bright band in the upper left of the images is a pine forest, running parallel to the along-track direction of the radar. The radar beam was incident from the upper side of the images. The length of the forest was about 170 m and the width of it was about 25 m. Both sides (upper and lower in the images) of the forest



L-HH, 64° C-VV, 62° X-HH, 64°

Fig. 1. SAR images.

Fig. 2(a) Pine forest imaged in Fig. 1.

Fig. 2(b) Inside the forest.

were cultivated soil fields. The upper side was very rough and the lower side was slightly rough. In Fig. 1, we observe that the pine forest has no shadow in the L band image, while it has a clear dark shadow in the C and X band images. We have observed the similar behavior on other pine forests in this area. Fig. 2(a) is a photograph of the pine forest imaged in Fig. 1, and Fig. 2(b) shows an inside of the forest.

Sieber and Noack (1986) mention a similar observation in the images obtained in the European Convair-580 campaign; that is, shadow of forests is obscure in the L band, while it is clear in the X band.

3. Backscatter from Forests

It is known that leaves of trees are almost transparent for the L band microwave. Backscatters from trees at the L band are mainly from branches and trunks, and leaves contribute to backscatter little. Considering these characteristics, we have listed up the processes which would constitute a backscatter from pine forests at the L band:

(1) Single scattering at branches and trunks.
(2) Direct backscatter from ground surfaces. (Attenuation occurs while passing through trees. The attenuation is mostly due to absorption and scattering by branches and trunks.)
(3) Multiple scattering among branches and trunks. We devide this process into two:
   a. Scattering elements are within one resolution cell of a SAR.
   b. Scattering elements are in different resolution cells.
(4) Corner-reflector reflection by a vertical trunk and a ground surface.
(5) Triple scattering composed of twice forward scatterings by branches and trunks and a backscatter from a rough ground surface.

The pine forest imaged in Fig. 1 has a width of about 25 m and a height of 12 to 13 m. The area that corresponds to the geometrical shadow of the forest for the incoming radar beam was a slightly rough soil surface. Among the processes mentioned above, processes that could focus on this geometrical shadow area in the correlated image are (2), (3b) and (5).

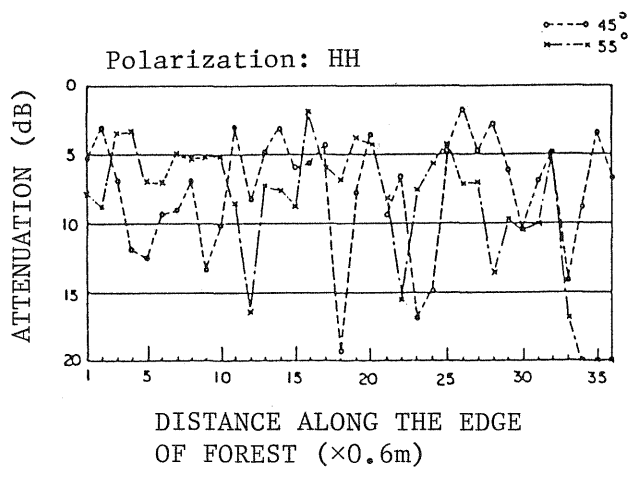


Fig. 3. One-way attenuation through the pines at L-band.

The measurement of the transmittance of tree canopies mentioned in the introduction was carried out in the agricultural field of the Tsukuba University, together with other sites. In this area, a measurement was made on a pine forest which had almost the same tree height and tree stand density as the forest imaged in Fig. 1. Fig. 3 is a result of the measurement for the HH polarization and the incidence angles of 45° and 55° (Murata, et al., 1987b). The path contained one or two tree-stands. The attenuation (one way) takes diverse values from 2 to 20 dB; typical values are, let us say, from 5 to 10 dB. A result of the measurement on the VV polarization was almost similar. Looking at Fig. 3, we note that, even when we take 5 dB as a representative value, a contribution of the process (2) to make no shadow is quite small; the direct backscatter from the soil surface reduces 10 dB by passing through the pine forest.

4. Multiple Scattering Among Trees

Dominant scatterers of trees at the L band are branches and trunks. Besides directly-backscattered waves from branches and trunks, multiply scattered waves, scattered by branches and trunks many times, may arrive at a receiving antenna of the radar. For simplifying the problem, let us consider a twice scattering. A wave scattered twice takes more time to come back to the radar antenna comparing to a directly scattered wave. The difference is roughly equal to the time that a wave propagetes between the first and the second scatterers. If the distance between the two scatterers are large (several times or more of a spacial resolutin of a SAR), the twice-scattered wave may seem to be originated from a ground surface behind the forest. To consider whether this process contributes for the pine forest to have no shadow, we have studied the followings:

(1) Is the twice-scattered wave focussed by the chirp compression and the aperture synthesis ? If focussed, where on a SAR image ?

(2) What is a ratio of the power of the twice-scattered components to the power from the forest ?

Fig. 4 shows a geometry. A_1 and A_2 are scattering points. A radar flies on the X-axis. The x-axis is on a ground plane and passes near the observed area. The y-axis is on the slant range plane. The distance between the X and x axes is r_o. Under conditions, which are satisfied in real SAR geometry, that

$$|y_1|,\ |z_1|,\ |y_2|,\ |z_2| << r_o$$

we have derived, by simple theoretical considerations, that:

a. The chirp pulse is focussed at $y = (y_1 + y_2 - r_{12})/2$.

b. The twice-scattered wave is really focussed by the aperture synthesis. The position of the focus is $x = (x_1 + x_2)/2$.

c. A total power (sum) of the twice-scattered components is roughly estimated by

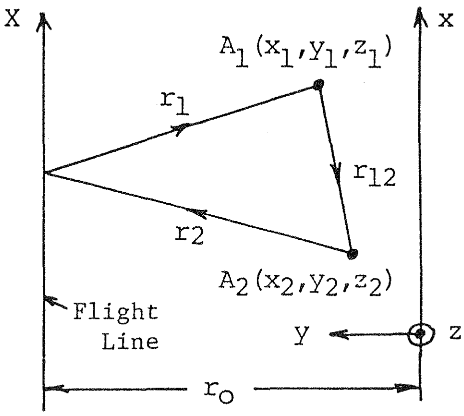


Fig. 4. Twice scattering

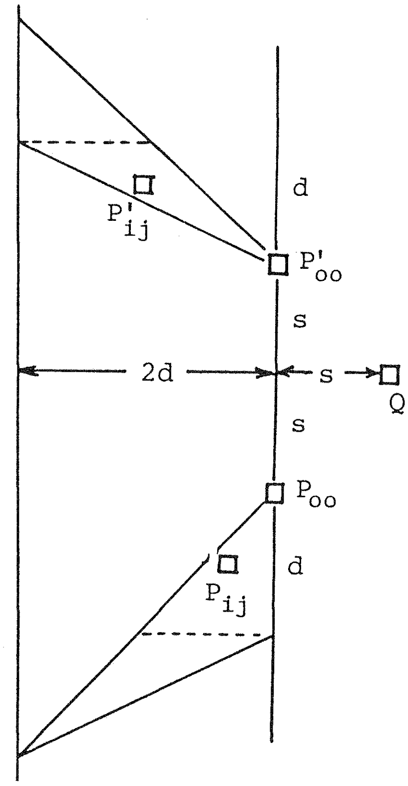


Fig. 5. Scatterer pairs in twice scattering

[Sum of twice-scattered power focussed on Q]
/ [Power of the forest on an image]

$$= 4 \sum_{ij} (\sigma^o \Delta a \Delta b / r_{ij}^2)$$

where Q is a small area $\Delta a \Delta b$ on the ground behind the forest (see Fig. 5), the distance between which and the edge of the forest is s. We count all scatterer pairs, P_{ij} and P'_{ij}, which focus on Q. The area of P_{ij} and P'_{ij} is taken to be $\Delta a \Delta b$. In the equation, the summation is taken over all scatterer pairs. σ^o is a scattering coefficient of the forest.

We have numerically calculated the twice-scattered power: the power which seems to be generated from the geometrical shadow region. Fig. 6 shows the result; the twice-scattered power is given in a graph which shows the power profile around the forest derived from the L-band SAR image. In the calculation of the twice-scattered power, we have assumed that the scattering coefficient of the forest is -10 dB.

We see in Fig. 6 that the twice-scattered power is fairly large and the power near the edge of the forest is almost equal to the power observed in the real SAR image. But in the region far from the edge, the twice-scattered power is quite insufficient to explain the really-observed power.

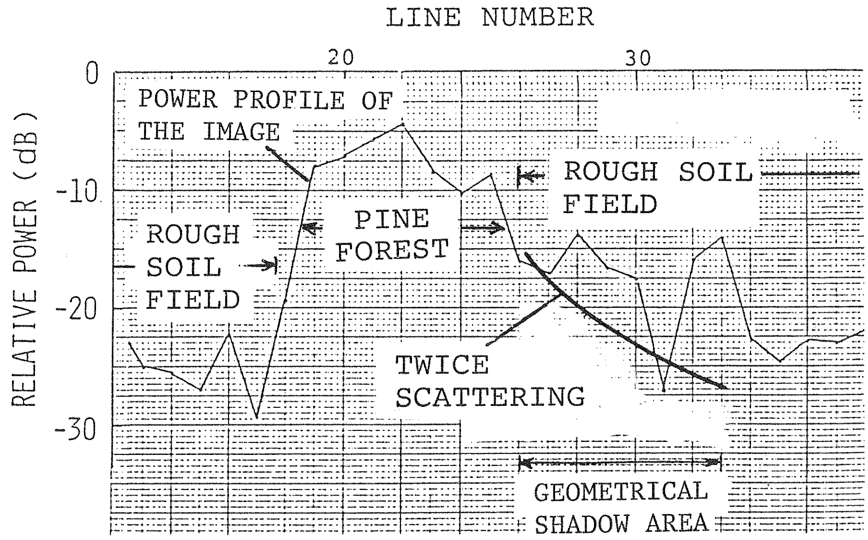


Fig. 6. Estimated twice-scattered power and power profile of the SAR image.

5. Forward Scattering by Trees

Fig. 7 is power profiles in the goemetrical shadow region, which are derived from Fig. 6 by converting the scale of the power into linear. In the figure, we have added the direct-backscatter component from the ground surface; in estimating this ground scatter component, we have assumed that the ground itself had scattered at a level of G in the figure and that the two-way attenuation due to trees was 10 dB. We see in Fig. 7 that there remains a fairly large power to be explained by some other scattering mechanisms. A remaining possible process is (5) mentioned in 3.

Thus we postulate the third process to explain the remaining power mentioned above, in which a forward scattering plays an important role.

When a plane electromagnetic wave is scattered by a cylinder, an angular distribution of the scattered power is isotropic if a diameter of the cylinder is very small comparing to the wavelength (λ) of the wave; but when the diameter increases and its circumferencial length becomes nearly the same or larger than the wavelength, a forward scattering becomes dominant. Fig. 8 is a scattering angle dependence of the radar cross-section of a dielectric cylinder with a circumferencial length of 1.676λ and a permittivity of $10+j5.0$.

When a radar illuminates thick branches and trunks obliquely, most of the waves, scattered by the branches and trunks in forward directions, hit a ground surface behind trees. If the ground surface is rough, backscattered waves are generated, and these backscattered waves can come back to the radar by being scattered again by branches and/or trunks in forward directions. This is the process (5) mentioned in the section 3. The waves may be focussed in the behind of the forest in a SAR image. In this process, a wave can propagate along one path in inverse way, so two signals, propageted along the same path in inverse each other, are added coherently at a radar receiver.

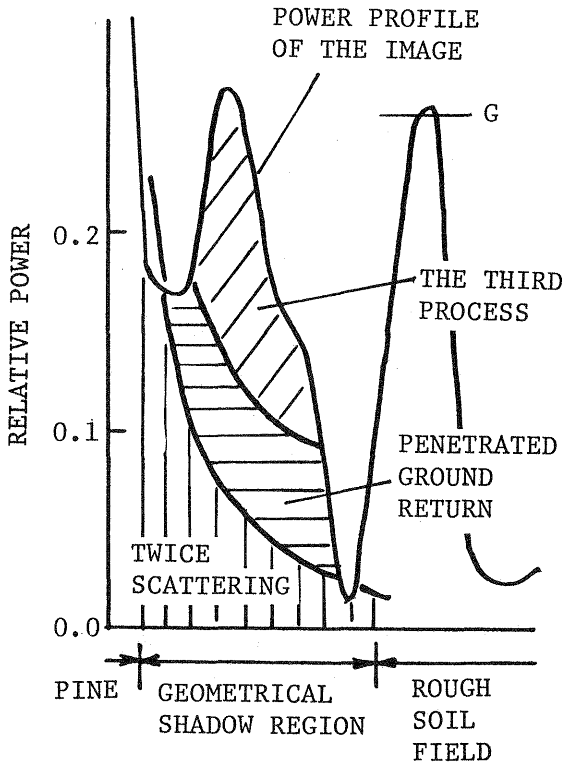


Fig. 7. Power profiles in the geometrical shadow region.

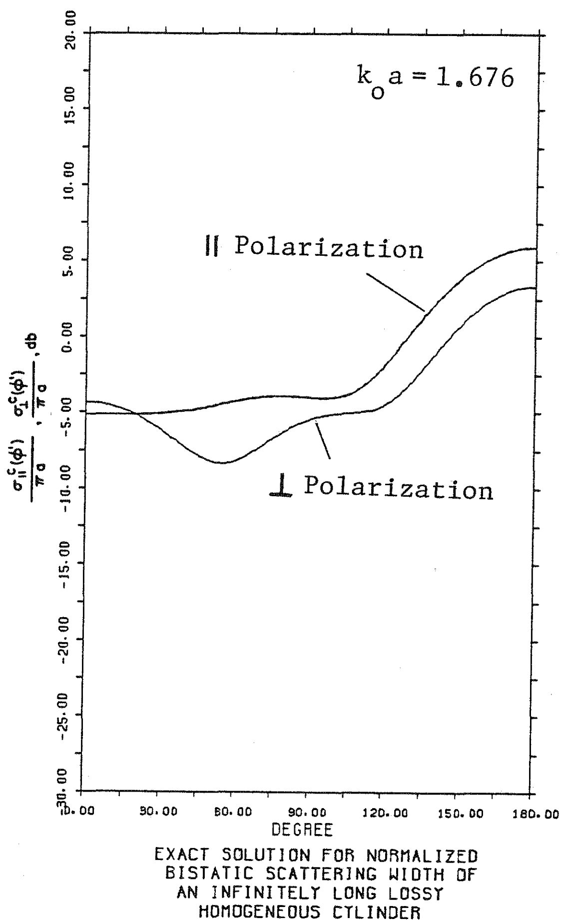


Fig. 8. Radar cross section of a dielectric cylinder.

The process mentioned above is a triple scattering and it might be seem to be a higher order process. But we should note that in the forward scattering a loss of total power is small, so in this triple scattering, a loss of power, in total, is not "very" small compared to the direct backscatter from a rough surface. An unusual point is that backscattered powers from a large distributed surface, much larger than one resolution cell, are incoherently added in one resolution element on a SAR image. So two-dimensional σ^o pattern of a ground surface is lost in this scattering process.

Thus we can expect that the triple scattering postulated here is near to the first order process. Though quantitative analysis of this process is quite comlex, we can say that, since a combination of the attenuated direct backscatter (the process (2)) and the multiple scattering (the process (3b)) are not sufficient to explain the "no"-shadow problem, the remaining triple scattering, composed of twice forward scatterings and a rough surface backscatter, is a promising candidate to solve the "no"-shadow problem.

6. Conclusions

We have discussed the reason why pine forests have no shadow in the L band SAR image. Though the discussions are not fully quantitative, we have shown that three processes, an attenuated direct backscatter from a rough surface behind forests, a multiple scattering among branches and trunks, and a triple scattering, composed of twice forward scatterings by branches and trunks and a rough surface backscatter, worked to generate an apparent backscattter from the geometrical shadow area behind pine forests.

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