Retrieval of the Effective Soil Moisture Contents as a Ground Truth from Natural Soil Surfaces

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Abstract: A method for retrieving effective soil moisture contents from natural soil surfaces is proposed in this paper. Natural soil surfaces usually have various types of soil moisture depth profiles. The transmission and reflection coefficients of the homogeneous soil surfaces were examined. The backscatter from a two-layered rough surface was also examined in this study. From those examinations, it can be concluded that only the top 0-1 cm layer of soil surfaces influence the backscatter even for an extremely dry surface, and the effective soil moisture can be obtained from the 1 cm surface layer for L-band, and the top surface layer for C- and X-band frequencies.

1. Introduction

The moisture depth profiles of natural soil surfaces have various shapes[1] as shown in Fig. 1.

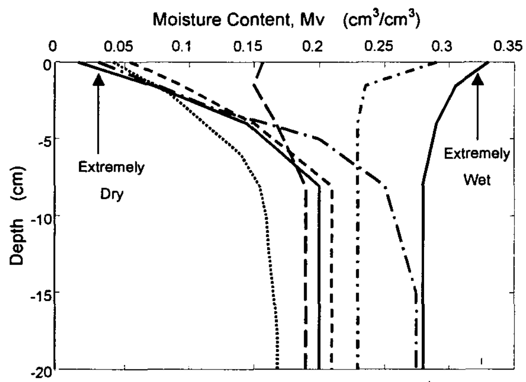


Fig. 1. Measured soil moisture depth profiles.

The effective soil moisture content may be defined as a function of frequency because the penetration depths depend on frequency. Because the wave penetrates deeper in a dry surface, the extremely dry surface in Fig. 1 was examined in detail.

2. Theoretical Computation

An extremely dry surface was selected from Fig.1 as shown in Fig. 2. Fig. 2(b) shows a large number of infinitesimally thin layers, which are obtained from a measured moisture profile, Fig. 1(a).

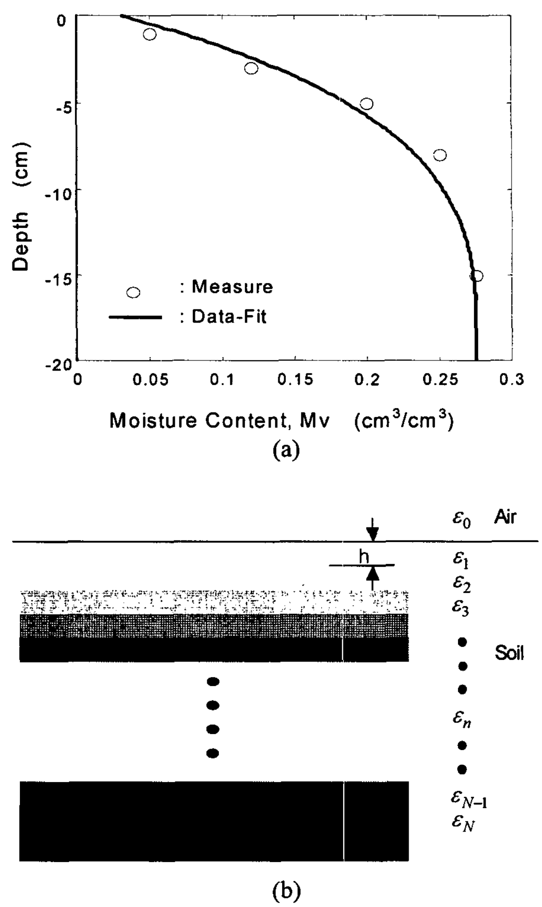


Fig. 2. Moisture depth profile for an extremely dry surface; (a) measured profile and (b) layered profile.

Then, the transmission coefficient T and the reflection coefficient R of the layered soil surface can be computed as follows:

$$T = v_{22} - v_{12}v_{21}/v_{11}, \quad R = -v_{12}/v_{11}, \qquad (1)$$

where $\overline{\overline{V}}_{t0} = \overline{\overline{V}}_{tn} \cdot \overline{\overline{V}}_{nn-1} \cdots\cdots \overline{\overline{V}}_{10} = \begin{bmatrix} v_{11} & v_{12} \\ v_{21} & v_{22} \end{bmatrix}$,

$$\overline{\overline{V}}_{l+1,l} = \frac{1}{2}\left(1+p_{l+1,l}\right)\begin{bmatrix} e^{[-ik_{l+1,l\,z}h]} & R_{l+1,l}e^{[-ik_{l+1,l\,z}h]} \\ R_{l+1,l}e^{[ik_{l+1,l\,z}h]} & e^{[ik_{l+1,l\,z}h]} \end{bmatrix},$$

$$R_{l+1,1} = \frac{1-p_{l+1,l}}{1+p_{l+1,l}},\quad p^{TE}_{l+1,l} = \frac{k_{lz}}{k_{l+1z}},\ p^{TM}_{l+1,l} = \frac{\varepsilon_{l+1}k_{lz}}{\varepsilon_l k_{l+1z}},$$

$$k_{lz} = \sqrt{k_l^2 - k_0^2 \sin^2\theta_i}\ .$$

The penetration depth is defined as the depth where the wave attenuated by $\exp[-1]$ after transmission. The penetration depths for the moisture profile of Fig. 2 are 9.9 cm, 4.3 cm and 2.4 cm for 1.25 GHz, 5.3 GHz, and 9.6 GHz, respectively, as shown in Fig. 3.

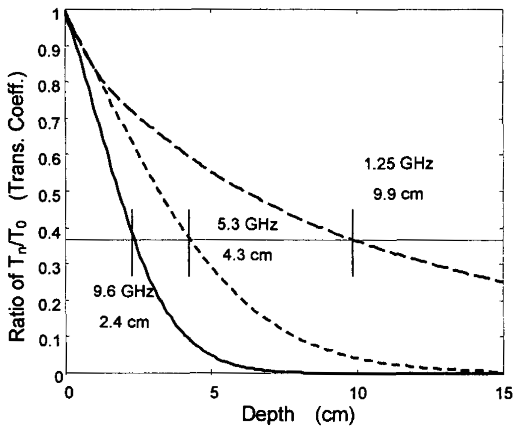
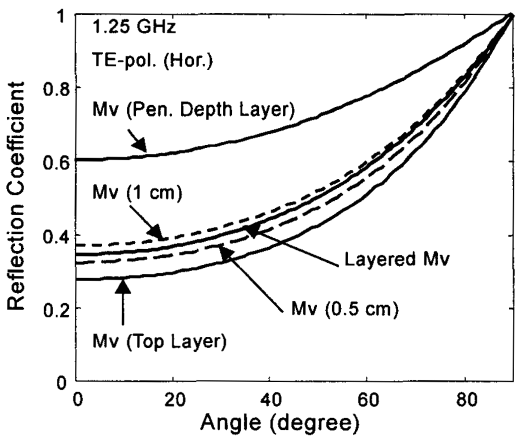
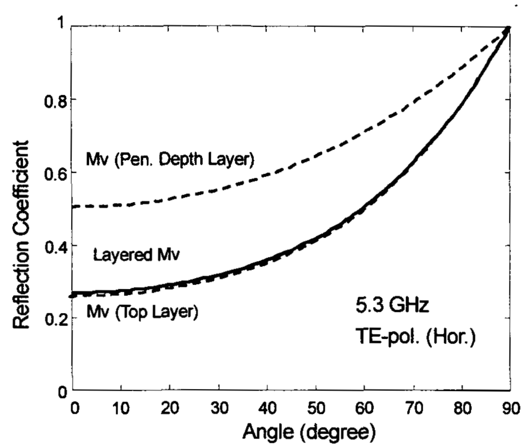


Fig. 3. Penetration depths at three different frequencies.

Fig. 4 shows the reflection coefficients of the moisture profile at 1.25 GHz and 5.3 GHz, respectively.



(a)



(b)

Fig. 4. Reflection coefficients at (a) 1.25 and (b) 5.3 GHz.

At 5.3 GHz, the reflection coefficient is same with that of a uniform soil with the Mv of the top layer as shown in Fig. 4(b). Fig. 4(a) shows that the effective soil moisture may be the soil moisture of the top 0-1 cm layer at 1.25 GHz, even though the penetration depth is 9.9 cm.

3. Numerical Computation

Since no theoretical models exist that can adequately predict the backscattering coefficient from a multi-layered inhomogeneous rough surface, the backscatter from a two-layered rough surface as shown in Fig. 5 was examined numerically in this study.

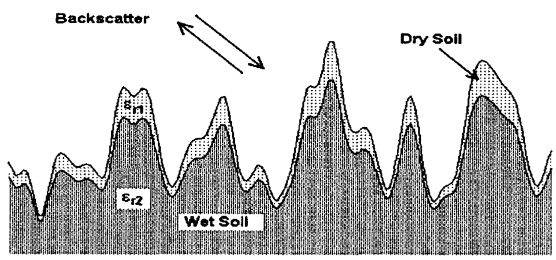


Fig. 5. Backscattering from a two-layered rough surface.

A set of governing integral equations can be derived from the wave equations and the boundary conditions for computation of the scattered field [3].

$$\int_{C0}\left\{E_{0y}(\bar{\rho}')\frac{\partial G_{2d0}(\bar{\rho},\bar{\rho}')}{\partial n_0} - G_{2d0}(\bar{\rho},\bar{\rho}')\frac{\partial E_{0y}(\bar{\rho}')}{\partial n_0}\right\}dl = E^i_y(\bar{\rho},\bar{\rho}'),\bar{\rho}' \in C_0 \quad (2)$$

$$\int_{C0}\left\{E_{0y}(\bar{\rho}')\frac{\partial G_{2d0}(\bar{\rho},\bar{\rho}')}{\partial n_0}-G_{2d0}(\bar{\rho},\bar{\rho}')\frac{\partial E_{0y}(\bar{\rho}')}{\partial n_0}\right\}dl$$
$$-\int_{C1}\left\{E_{1y}(\bar{\rho}')\frac{\partial G_{2d1}(\bar{\rho},\bar{\rho}')}{\partial n_1}-G_{2d1}(\bar{\rho},\bar{\rho}')\frac{\partial E_{1y}(\bar{\rho}')}{\partial n_1}\right\}dl=0,\ \bar{\rho}'\in C_0$$

$$\int_{C0}\left\{E_{0y}(\bar{\rho}')\frac{\partial G_{2d0}(\bar{\rho},\bar{\rho}')}{\partial n_0}-G_{2d0}(\bar{\rho},\bar{\rho}')\frac{\partial E_{0y}(\bar{\rho}')}{\partial n_0}\right\}dl$$
$$-\int_{C1}\left\{E_{1y}(\bar{\rho}')\frac{\partial G_{2d1}(\bar{\rho},\bar{\rho}')}{\partial n_1}-G_{2d1}(\bar{\rho},\bar{\rho}')\frac{\partial E_{1y}(\bar{\rho}')}{\partial n_1}\right\}dl=0,\ \bar{\rho}'\in C_1$$

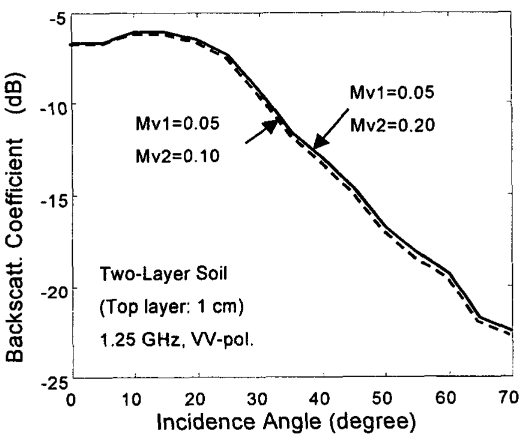
$$\int_{C1}\left\{E_{1y}(\bar{\rho}')\frac{\partial G_{2d2}(\bar{\rho},\bar{\rho}')}{\partial n_1}-G_{2d2}(\bar{\rho},\bar{\rho}')\frac{\partial E_{1y}(\bar{\rho}')}{\partial n_1}\right\}dl=0,\ \bar{\rho}'\in C_1$$

where $E_{0y}(\bar{\rho}')$, $\frac{\partial E_{0y}(\bar{\rho}')}{\partial n_0}$, $E_{1y}(\bar{\rho}')$, $\frac{\partial E_{1y}(\bar{\rho}')}{\partial n_1}$ are unknowns to be found.

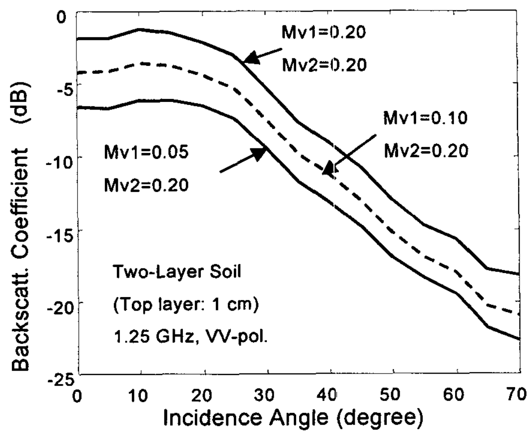
Then, the integral equations can be cast into a matrix equation using the method of moment as follows:

$$\begin{bmatrix}[Z_{11}^{mn}] & [Z_{12}^{mn}] & [0] & [0]\\ [Z_{21}^{mn}] & [Z_{22}^{mn}] & [Z_{23}^{mn}] & [Z_{24}^{mn}]\\ [Z_{31}^{mn}] & [Z_{32}^{mn}] & [Z_{33}^{mn}] & [Z_{34}^{mn}]\\ [0] & [0] & [Z_{43}^{mn}] & [Z_{44}^{mn}]\end{bmatrix}\cdot\begin{bmatrix}[I_1^n]\\ [I_2^n]\\ [I_3^n]\\ [I_4^n]\end{bmatrix}=\begin{bmatrix}[V_1^m]\\ [0]\\ [0]\\ [0]\end{bmatrix} \quad (3)$$

A random surface having the rms height of 1.9 cm and the Gaussian correlation with correlation length of 11.6 cm has been generated. Then, the height of the first layer varies from 1.8 cm to 0.2 cm (mean value of the height is 1 cm). Fig. 5 shows that the backscattering coefficient does not change when the moisture content of the lower soil varies from 0.05 to 0.30 cm^3/cm^3. The backscattering coefficient depends only on the moisture content of the top 1 cm layer as shown in Fig. 6.



(a)



(b)

Fig. 6. Backscattering coefficient from layered rough surface; effects of (a) the bottom layer and (b) the top layer.

4. Conclusion

Theoretical examinations were performed to obtain the penetration depths, the reflection coefficients for soil surfaces having inhomogeneous moisture depth profiles. The backscattering coefficients from a two-layer soil surface were also computed numerically at microwave frequencies for various values of moisture contents of both layers.

Based on those examinations, it could be concluded that the effective soil moisture can be obtained from the surface 1cm layer for L-band, and the just-top surface (or a very thin top layer of the surface) for C- and X-band frequencies.

References

[1] F.T. Ulaby, P.P. Batlivala and M.C. Dobson, "Microwave backscatter dependence on surface roughness, soil moisture, and soil texture", IEEE Trans. Geoscience Remote Sens., Vol. GE-16, pp.286-295, Oct. 1978.

[2] J.A. Kong, Electromagnetic Wave Theory, John Wiley & Sons, 1990.

[3] T. Wu and L.L. Tsai, "Electromagnetic fields induced inside arbitrary cylinders of biological tissues", IEEE Trans. Microwave Theory Tech., No.1, pp. 61-65, January 1977.