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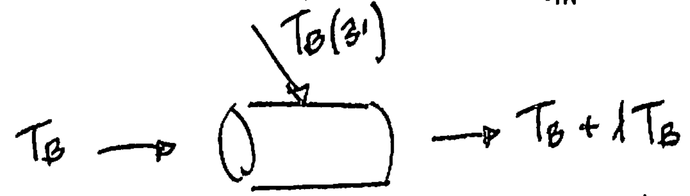
Microwave Radiometry of Earth's Surface: Realistic Considerations

We have so far considered only "perfect dielectrics" when considering a soil or ocean surface.
Perfect dielectric = material whose $\mathrm{Im}\{n = \sqrt{\epsilon_r}\} = 0$, i.e. no loss or absorption of radiation.
Does a perfect dielectric emit radiation?

Consider radiative transfer:

isotropic scattering

$$dT_B = -\kappa_e T_B + \kappa_a T + \frac{\kappa_s}{4\pi}\int_{4\pi} T(\Omega')\, d\Omega'$$



think energy conservation: if there is no absorption, how can there be emission without a temperature change? There can't be!

Soil and ocean water are not perfect dielectrics. Otherwise they would not emit radiation!

Since $\mathrm{Im}\{n = \sqrt{\epsilon_r}\} \neq 0$,

- Snell's laws still hold, but must interpret differently (angle of refraction slightly different, evervescent waves)
- there is a layer of soil/water near the surface that contributes the majority of emitted radiation — emitting depth

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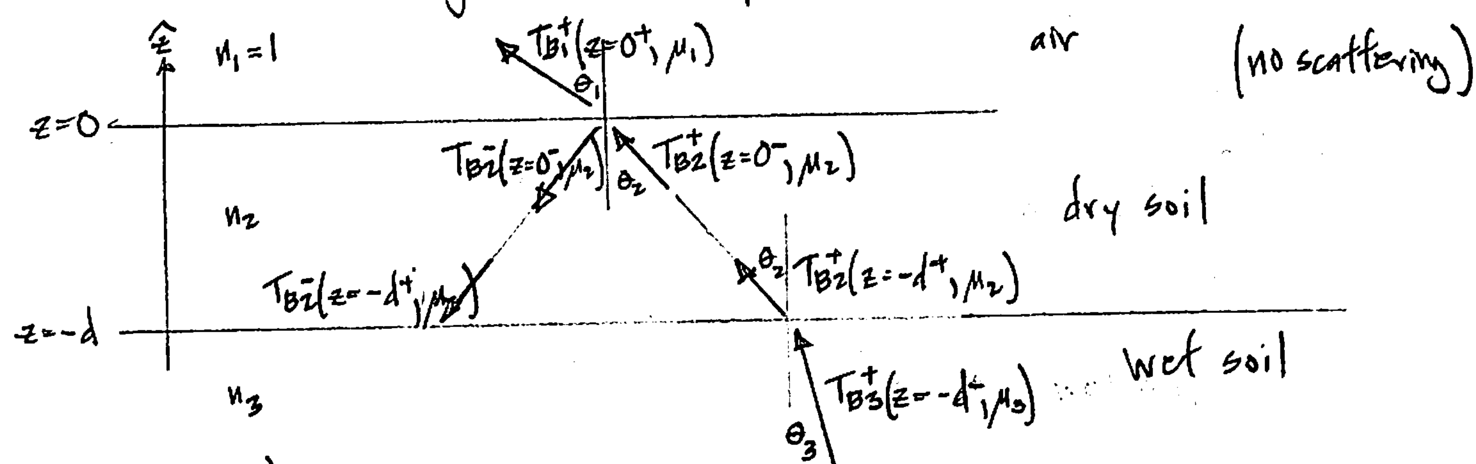
Layered Media

In reality, a soil or ocean is not isothermal and homogeneous. Temperature changes with distance into these two media, which will change the electrical properties of the media.

More significantly, chemical gradients (water in soil, salinity in ocean water) exists which also produce a change in electrical properties with depth.

One way to model these realistic situations is to use <u>multiple layers</u>.

* What is the brightness temperature of an isothermal two-layer medium?



$T_{B3}^{+}(z=-d^{-}, \mu_3) = \text{known}$

(1) $T_{B2}^{+}(z=-d^{+}, \mu_2) = \Pi_{p_{3-2}}\, T_{B3}^{+}(z=-d^{-}, \mu_3) + R_{p_{2-3}}\, T_{B2}^{-}(z=-d^{+}, \mu_2)$

(2) $T_{B2}^{+}(z=0^{-}, \mu_2) = \underbrace{T_{B2}^{+}(z=-d^{+}, \mu_2)\, e^{-\kappa_a d/\mu_2}}_{\text{extinction}} + \underbrace{T_0\left[1 - e^{-\kappa_a d/\mu}\right]}_{\text{emission}}$

(3) $T_{B2}^{-}(z=0^{-}, \mu_2) = R_{p_{2-1}}\, T_{B2}^{+}(z=0^{-}, \mu_2)$

(4) $T_{B2}^{-}(z=-d^{+}, \mu_2) = T_0\left(1 - e^{-\kappa_a d/\mu_2}\right) + T_{B2}^{-}(z=0^{-}, \mu_2)\, e^{-\kappa_a d/\mu_2}$

(5) $T_{B1}(z=0^{+}, \mu_1) = \Pi_{p_{2-1}}\, T_{B2}^{+}(z=0^{-}, \mu_2)$

5 equations
5 unknowns

see figure

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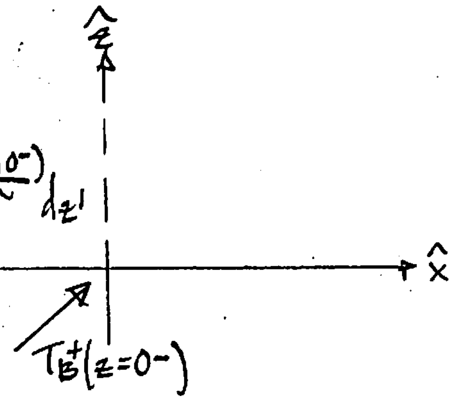
Emitting Depth

The layered medium example illustrated how there is a point at which a boundary between two layers with distinct electrical properties "can not be seen."

The <u>emitting depth</u> is the layer near the surface that contributes the majority of emitted radiation and therefor is the layer to which a microwave radiometer is sensitive to changes in the properties of that layer. It is "how far" a radiometer can "see into" a surface.

$$T_B^+(z=0^-) = \underbrace{T_B(-d)\, e^{-\frac{\tau(d,0^-)}{\mu}}}_{\text{attentuation}} + \underbrace{\int_{-d}^{0^-} \kappa_a(z')\, T(z')\, e^{-\frac{\tau(z',0^-)}{\mu}}\, dz'}_{\text{emission}}$$



there is some depth $z=-d$ at which the radiation doesn't reach the surface $\rightarrow$ emitting depth

The emitting depth scales with the optical depth, τ.

$$e^{-\tau}\Big|_{\tau=1} = e^{-1} = 37\%$$ % decrease in power level

$$\tau = 2k'' d_\tau \Rightarrow \text{when } \tau = 1, \quad d_\tau = \frac{1}{2k''} = \frac{1}{2k_0 n''} = \frac{1}{2\frac{2\pi}{\lambda_0} n''} = \frac{\lambda_0}{4\pi n''}$$

$$d_\tau = \text{depth of one optical depth} = \frac{\lambda_0}{4\pi n''}$$

<u>note that</u>: $d_\tau \sim \lambda_0$

$d_\tau \sim 1/n''$

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For water @ 19 GHz
($d_o = 0.016$ m)

$$d_T = \frac{0.016\text{ m}}{4\pi(2.5)} \approx 0.5\text{ mm}$$

For wet soil @ 19 GHz

$$d_T = \frac{0.016\text{ m}}{4\pi(1.0)} \approx 1\text{ mm}$$

For water @ 1.4 GHz
($d_o = 21$ cm)

$$d_T = \frac{0.21\text{ m}}{4\pi(0.3)} \approx 6\text{ cm}$$

For wet soil @ 1.4 GHz

$$d_T = \frac{0.21\text{ m}}{4\pi(0.1)} \approx 0.2\text{ m}$$

not very realistic

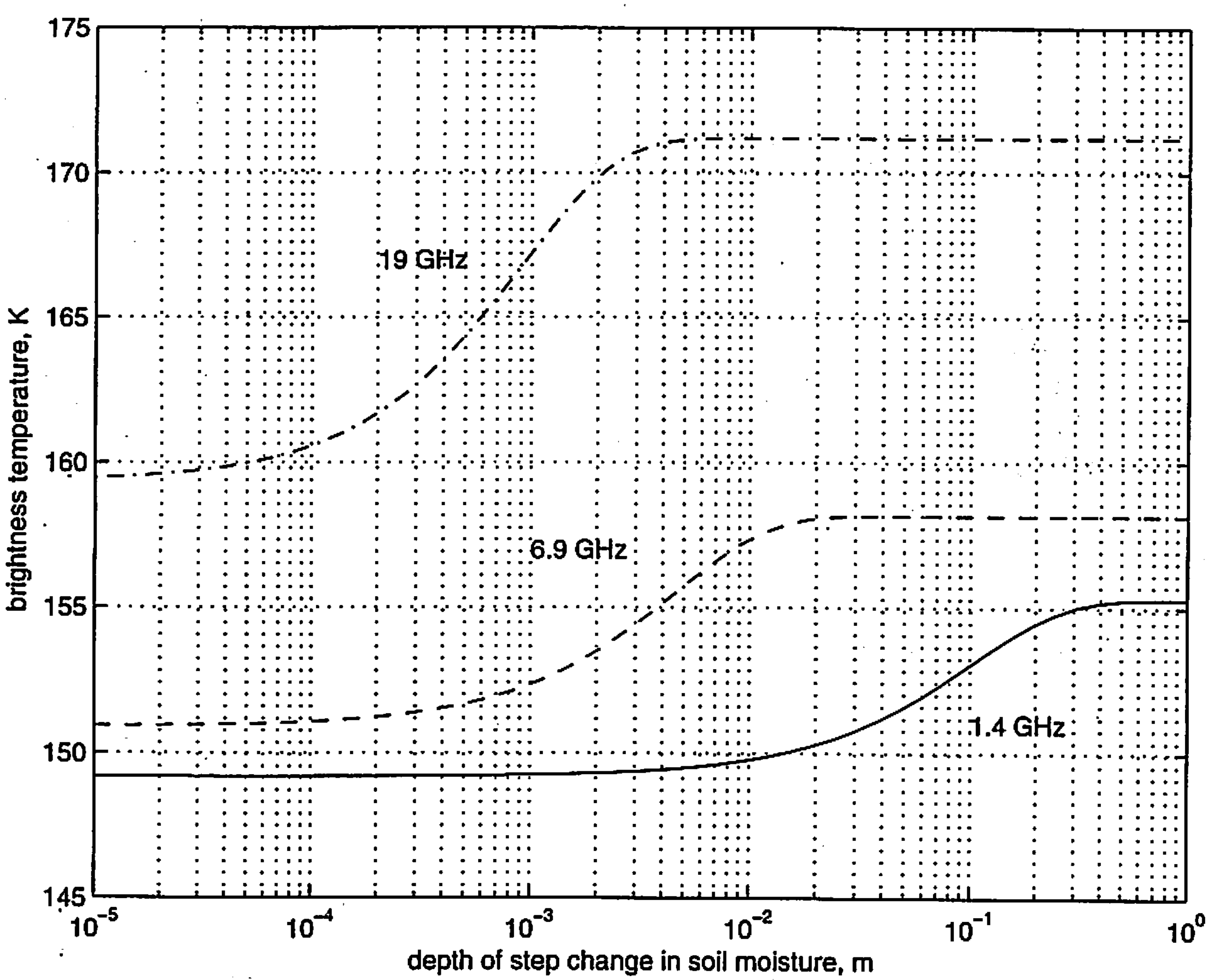
Other considerations

Effect of temperature gradients?

Effect of change in soil water content with depth (soil moisture gradient)?

Rule of thumb (empirical findings): emitting depth at 1.4 GHz is ~ 5 cm

can change with soil moisture conditions



175
170
165
160
155
150
145
brightness temperature, K
19 GHz
6.9 GHz
1.4 GHz
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
depth of step change in soil moisture, m