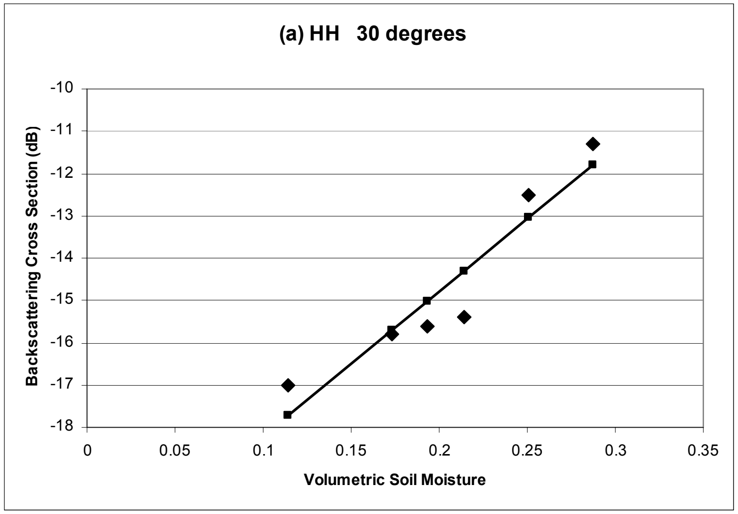
National Aeronautics and
Space Administration

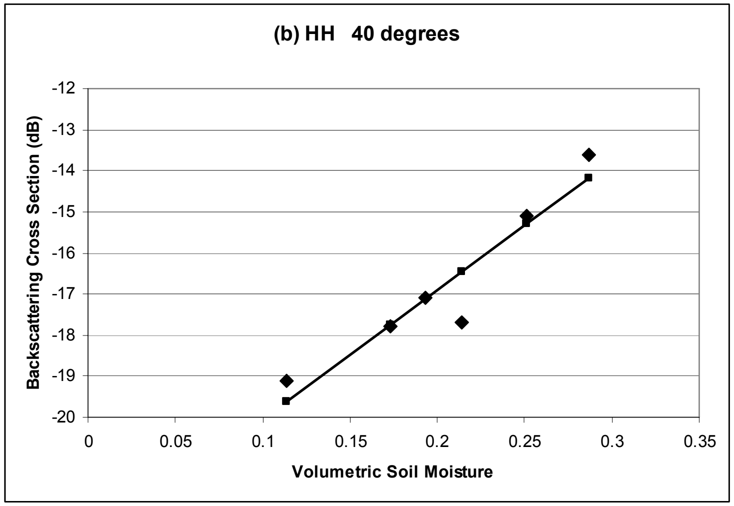
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

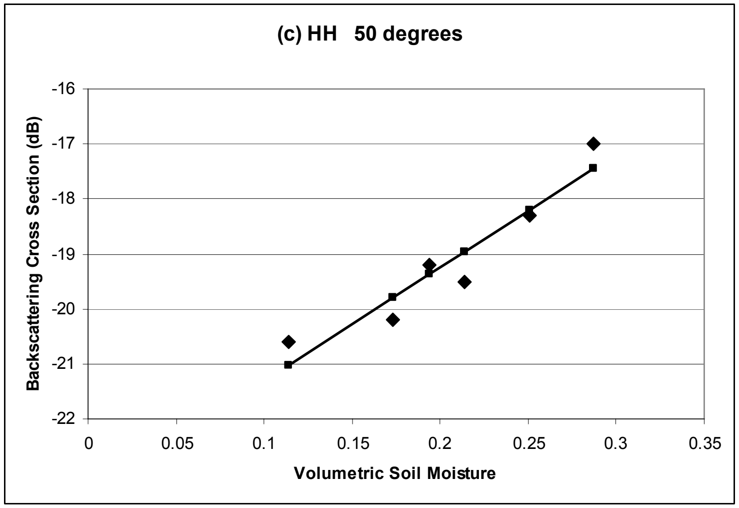
ESTIMATING SOIL MOISTURE FROM A VARYING SUBSURFACE PROFILE

Jakob J. van Zyl, Yunjin Kim and Uday Khankhoje
Jet Propulsion Laboratory,
California Institute of Technology,
Pasadena, California, USA

Motivation

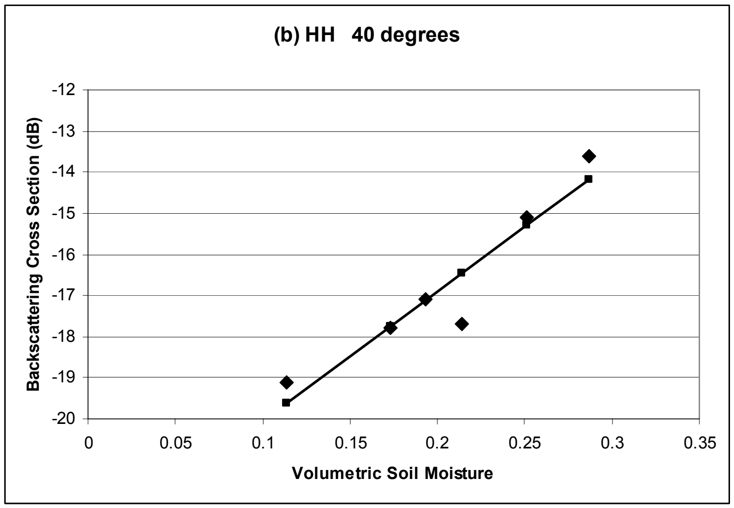


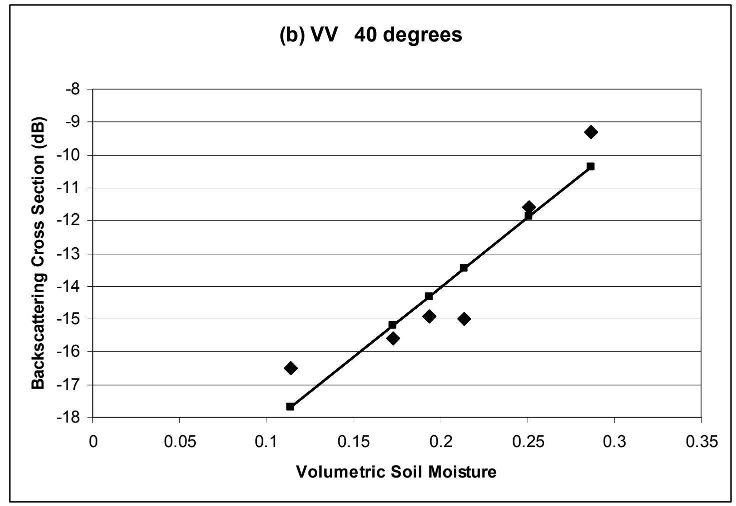




Data from Washita '92 Data Report,
http://www.ars.usda.gov/Research/docs.htm?docid=10087

Motivation (Cont.)





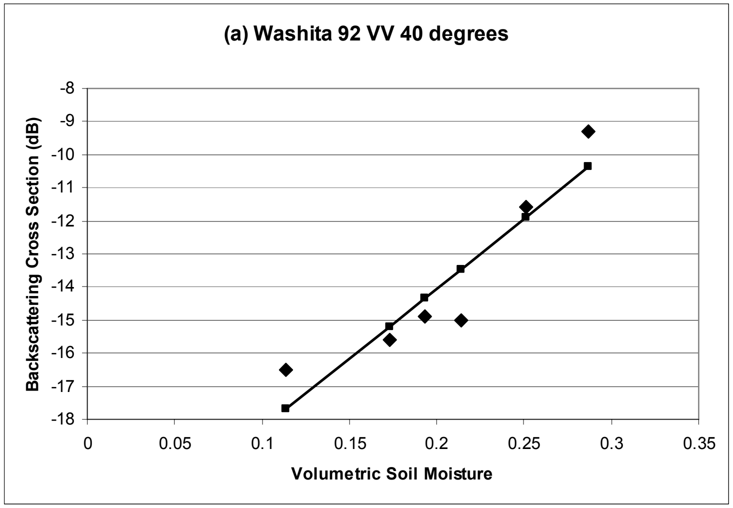
$$10\log_{10}(\sigma_{pp}) = Cm_v + D$$

	H-polarization		V-polarization	
Incidence angle	*C*	*D*	*C*	*D*
30 degrees	34.2	-21.6	45.8	-22.2
40 degrees	31.4	-23.2	42.2	-22.5
50 degrees	20.6	-23.4	36.0	-24.0

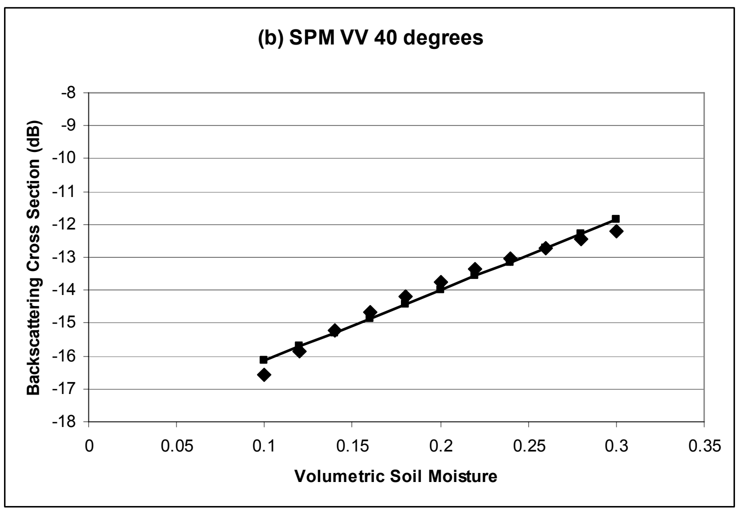
National Aeronautics and
Space Administration

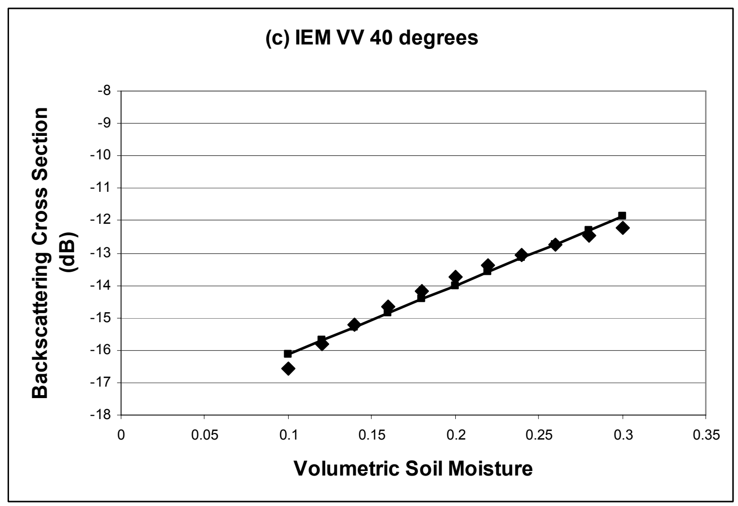
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Motivation (Cont.)



The sensitivity predicted by the models are nearly identical, but only about half of that observed in the experimental data





Time Series Analysis

The polarimetric backscattering cross section can be written as

$$\sigma_{pq} = f_{pq}(P_1, P_2, ..., P_N)$$

where (*i* = 1, 2, …, N) represents a remote sensing variable such as soil moisture, surface roughness, etc.

The time variation of the radar cross-section is calculated as

$$\frac{\partial \sigma_{pq}}{\partial t} = \sum_{i=1}^{N} \frac{\partial f_{pq}}{\partial P_i} \frac{\partial P_i}{\partial t}$$

Notice that the first term on the right represents the backscattering cross section sensitivity to physical quantities such as soil moisture. This is the term that was studied extensively to estimate soil moisture from polarimetric radar data. However, the time-series formulation has an additional term, that can be thought of as a temporal filter, which provides a weighting factor for each sensitivity. That is, if the time variation of a parameter such as soil texture and the vegetation structure is not significant enough to change a model function over a specified time scale, we can ignore the effect of that parameter on the temporal variation of the soil moisture.

Time Series (Cont.)

In the case of bare surfaces, the two main parameters that would vary over time are the surface roughness and the soil moisture. This means that we can approximate the time change in the radar cross-section as:

$$\frac{\partial \sigma_{pq}}{\partial t} \approx \frac{\partial f_{pq}}{\partial h}\frac{\partial h}{\partial t} + \frac{\partial f_{pq}}{\partial m_v}\frac{\partial m_v}{\partial t}$$

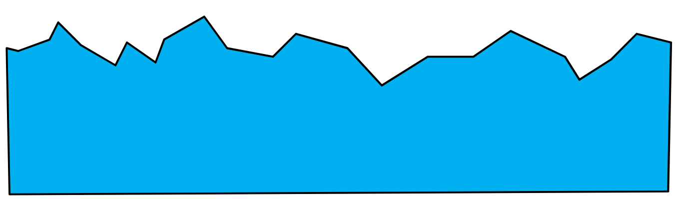
We shall now look at each of these terms separately in the context of the earlier data

Reference:

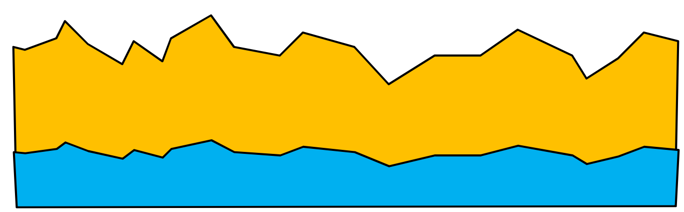
Y. Kim and J. J. van Zyl, “A Time-Series Approach to Estimate Soil Moisture Using Polarimetric Radar Data,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 47, pp. 2519–2527, August 2009.

Roughness Change

- The experimental data shows a larger sensitivity to changes in soil moisture than what the models predict if we only vary moisture in the models.
- If the roughness also changes in a way that is correlated with soil moisture, one could observe increased sensitivity.
- While this is unlikely, it is conceivable that for very wet surfaces, the actual rough surface will also represent the physical interface. As the surface dries, it is possible that some subsurface "wet horizon" may be the effective reflection surface. It is plausible that this horizon is a smoothed version of the actual surface. If true, this combination would enhance the apparent sensitivity to soil moisture changes.
- We believe this is an unlikely explanation for the discrepancy however, and further study is required to confirm or debunk this hypothesis.



Wet Surface



Dry Surface with subsurface wet horizon

Moisture Profile

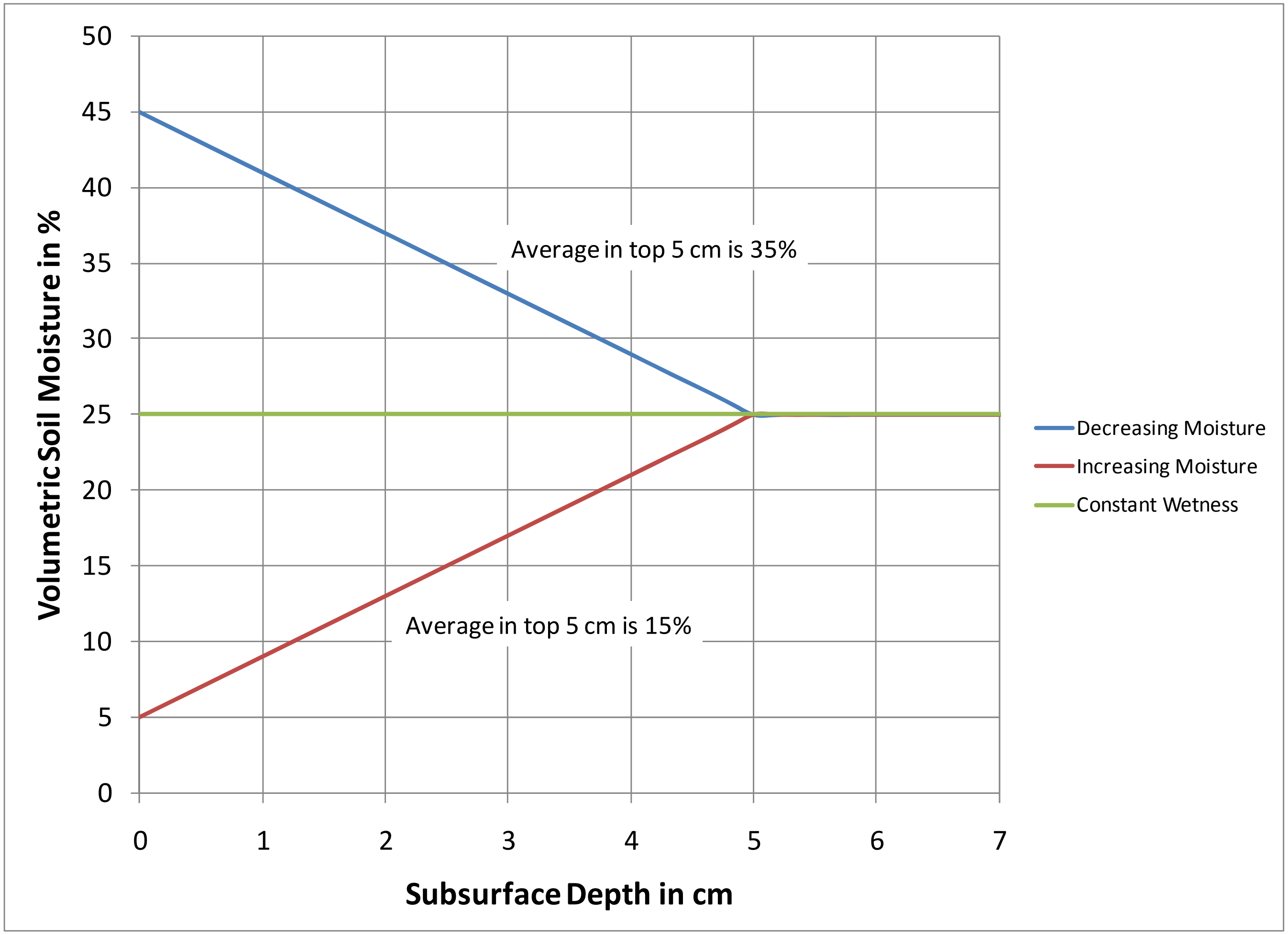
- We believe a more likely explanation comes from the possibility of a non-uniform subsurface moisture profile.

- The most common method to collect in-situ moisture information is to collect a soil sample in the upper 5 cm of soil. This sample is then dried and the average soil moisture is recorded.

- Time Domain Reflectometry probes also measure the total delay to a given depth, from which an average dielectric constant is calculated.

- If the subsurface moisture profile is not constant, the surface moisture value may be significantly different from the measured average value.

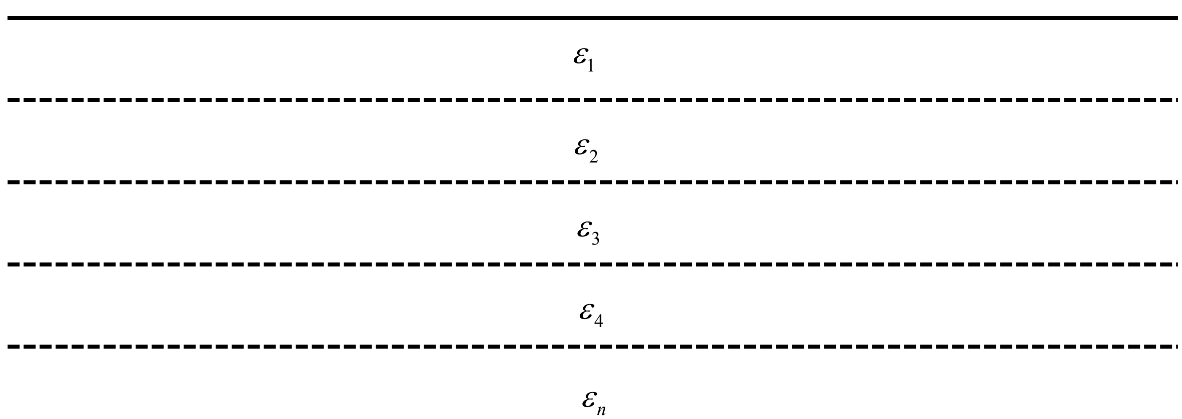
Moisture Profile



Moisture Profile

- To investigate the effect of a changing moisture profile, we calculated the reflection coefficient of a dielectric half space with a varying dielectric constant

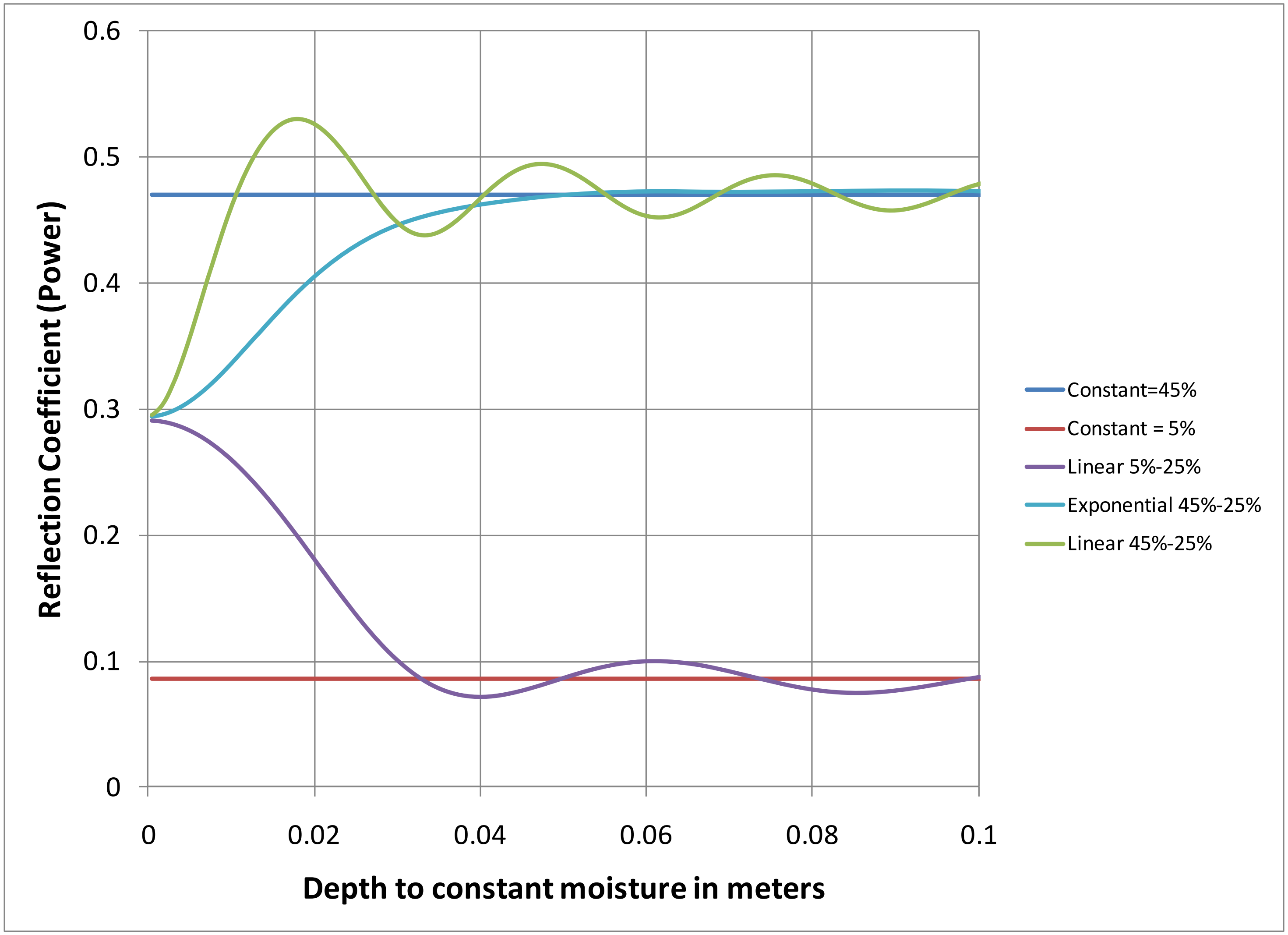
- The surface is modeled as a series of thin layers with constant but different dielectric constants. The transfer matrix method is then used to calculate the reflection coefficient at normal incidence.



National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Reflection Coefficient

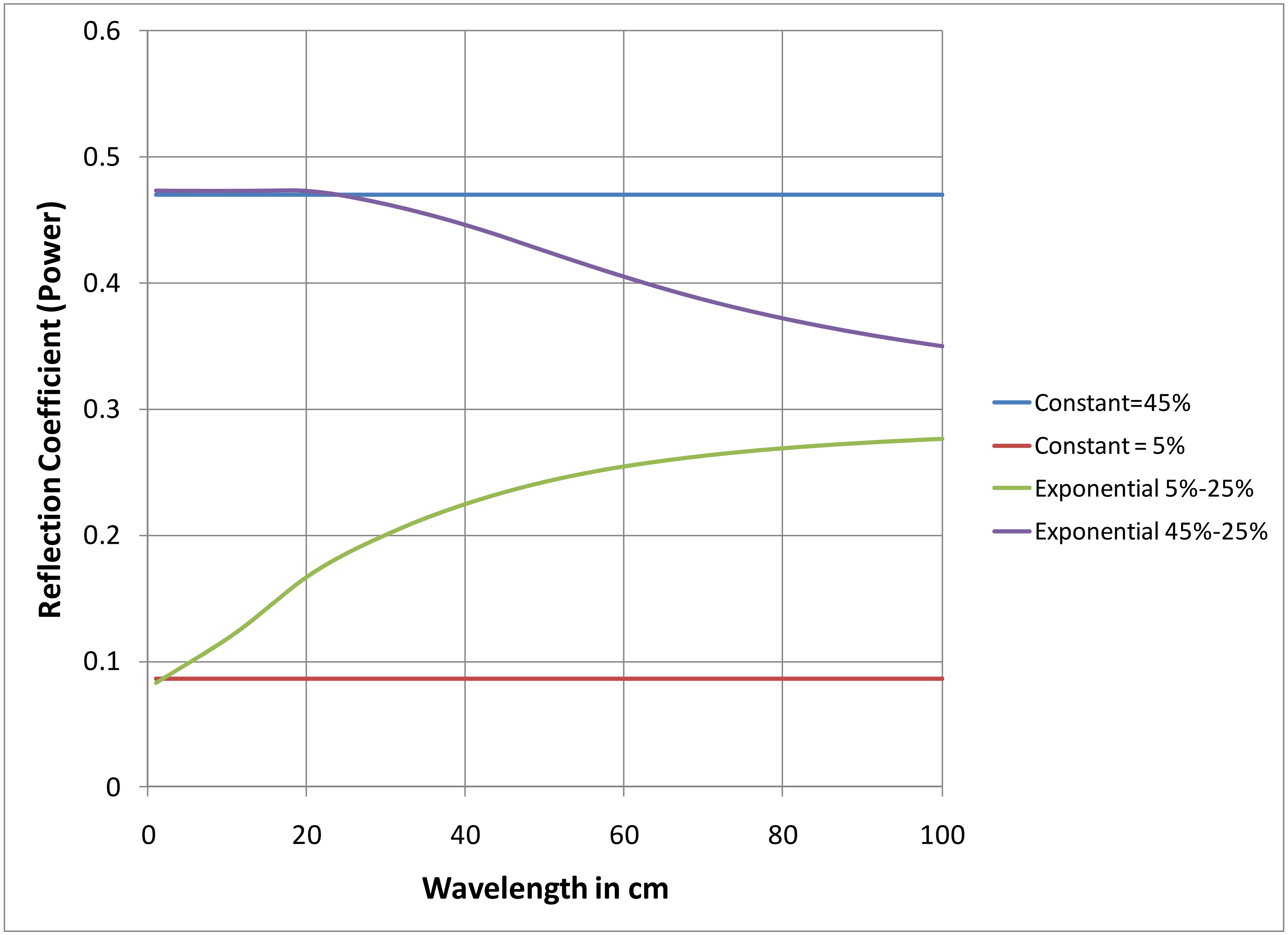


Wavelength = 24 cm

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Effect of Wavelength



Depth to constant moisture = 5 cm

Reflection Coefficient (Cont)

- The results show that for varying subsurface profiles, the reflection coefficient of a very thin layer is similar to that of the constant deep layer moisture.

- For layers where the varying part is a few cm thick, however, the reflection coefficient quickly approaches that of a constant layer with the same moisture *as the top moisture value only.*

- For the decreasing moisture profile example, this means the reflection coefficient is the same as that of a surface with a constant moisture profile of 45%. The in-situ measurement would have suggested an average moisture of 35%.

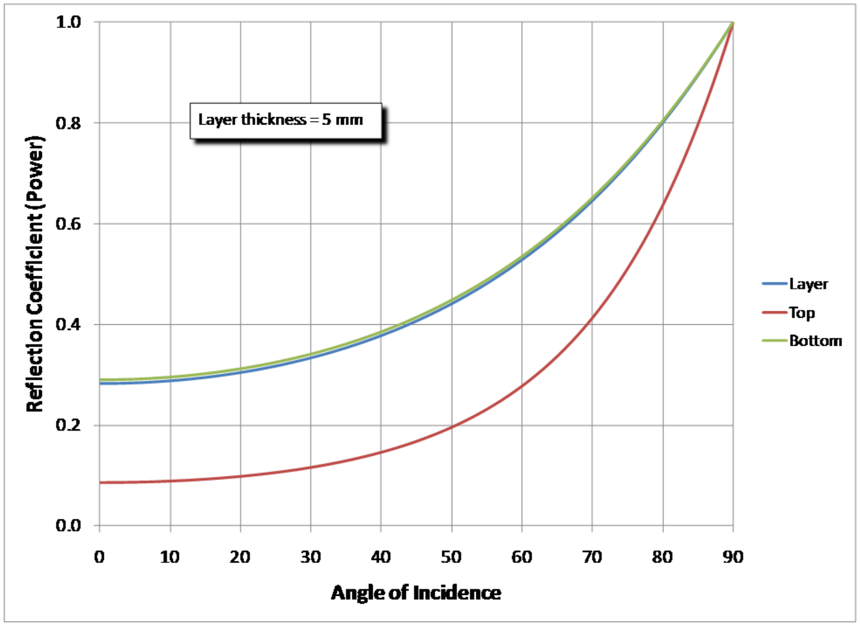
- Similarly, for the increasing moisture profile example, the reflection coefficient is the same as that of a surface with 5% moisture. The in-situ measurement would have suggested an average moisture of 15%.

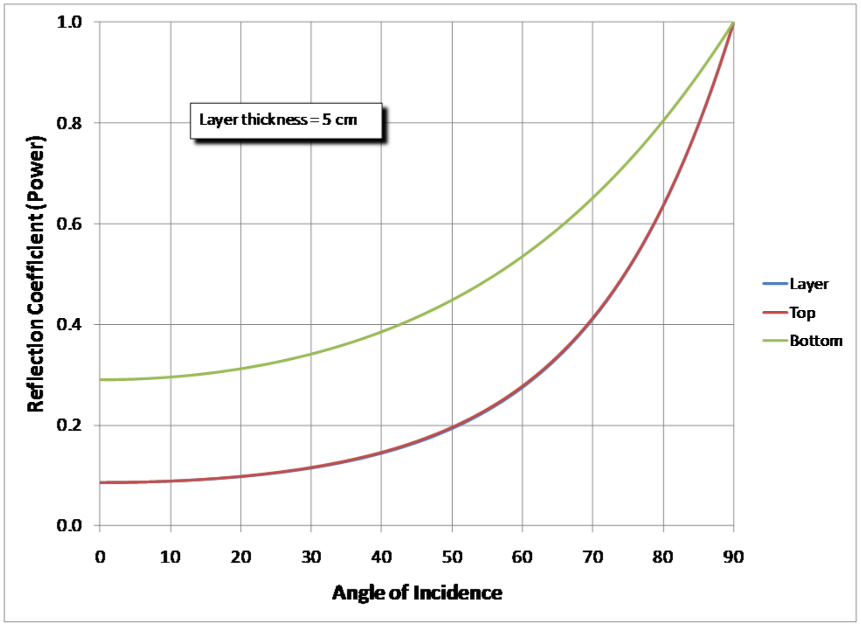
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Oblique Angles:

Horizontal Polarization





Wavelength = 24 cm

SPM Prediction

Using Hallikainen's dielectric formula for a sandy loam soil we find for a surface with rms height 1 cm, rms slope 7.5 degrees, exponential correlation function:

Moisture %	Dielectric Constant	Sigma HH	Sigma VV
5	3.7	-35.6	-32.2
15	8.0	-32.7	-28.0
25	14.4	-31.4	-26.0
35	22.8	-30.6	-24.8
45	33.2	-30.0	-24.0

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

SPM Prediction

Moisture Change	Cross-section Change HH	Cross-section Change VV
15% - 35% (average)	2.1 dB	3.2 dB
5% - 45% (top surface)	5.6 dB	8.2 dB

Assuming we use the average moisture numbers as our in-situ truth, the expected change(SPM) at HH would be 2.1 dB for a measured 20% change in moisture. If we use our reflection coefficient results, however, the radar would measure a change closer to 5.6 dB, indicating a sensitivity more than twice of the expected.

"Observed" Chh	33.0
SPM Chh	10.5
"Observed" Cvv	41.0
SPM Cvv	16.0

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Conclusions

- ❑ We investigated the effect of a varying subsurface moisture profile on the observed sensitivity to soil moisture.

- ❑ Current methods for measuring in-situ moisture may not accurately measure the surface soil moisture that corresponds to the effective dielectric constant responsible for the scattering of the radar waves.

- ❑ For a planar slab of varying dielectric, the reflection coefficient quickly approaches that of a homogenous slab with dielectric constant equal to the surface value of the varying profile

- ❑ If we simply apply this dielectric to the SPM, one would “observe” a much higher sensitivity to soil moisture than what the models would predict based on the in-situ measurements.

- ❑ The difference is a function of the difference between the average moisture measured in situ and the surface value.

- ❑ We are currently developing a numerical scattering model to test this hypothesis more rigorously.