Frequency Dependences of Microwave Emission of Soils with Roughness from 1.5 GHz to 37 GHz Based on Numerical Solutions of Maxwell Equations

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Outline

- Emission from Rough Surface
  - Soil Moisture and Exponential Correlated Surface
- Numerical method comparisons with
  - Kirchhoff Method
  - Small Perturbation Method
  - Advanced Integral Equation Model (AIEM) (single scattering only)
- frequency dependence: e, Δe (rough-flat), & Δe (TM-TE)
  - comparison between Gaussian and exponential correlated surfaces
  - comparison among different look angles
  - frequency correlation (L/C, X/C, Ku/C)
- Summary

Analytic Models for Rough Surface Scattering

- Kirchoff Approximation (KA)
- Small perturbation method (SPM2)
- Integral equation Model (IEM)
- Advance Integral equation Model (AIEM)
- Small Slope Approximation (SSA)
- Local Curvature Approximation (LCA)

  - Soil surfaces: Large slope with multiple scales; exponential correlation function
  - Models validity must be re-examed

Numerical Maxwell Model (NMM)

- Numerical Solutions of Maxwell equations (NMM2D)
- Computer Generate Realizations of Random Rough Surface; Solve Maxwell Equations for Each Realization; Take Statistical Average
- Capability Enhanced by Fast method of Solving Maxwell equations, e.g. SMCG, UV, UV_SMCG; O(NlogN) method (by Tsang's group of UW)

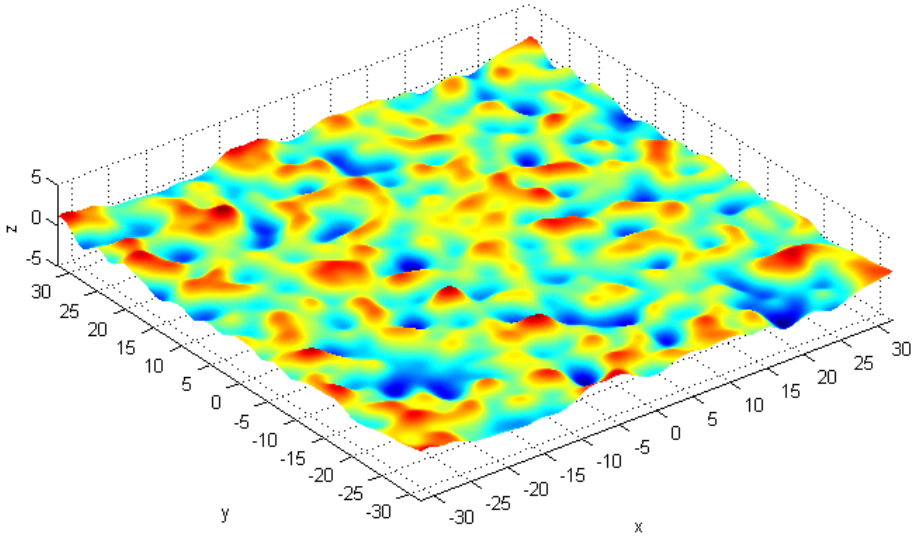
Fine scale features in exponential correlation function

Gaussian Correlation function :

$$C(x,y) = h^2 \exp\left(-\frac{x^2+y^2}{l^2}\right)$$

$$W(k) = \frac{h^2 l^2}{4\pi} \exp\left(-\frac{k^2 l^2}{4}\right)$$

rms height = 0.5
cl = 2.5

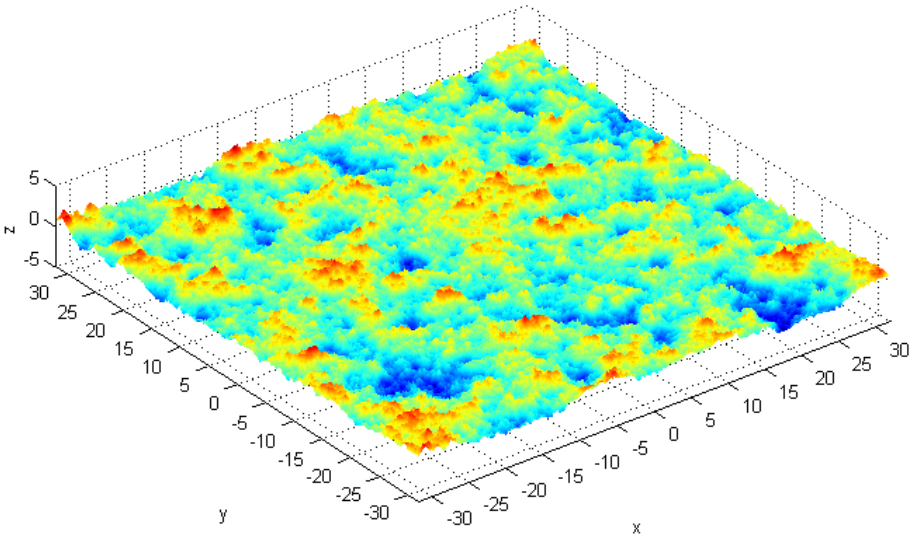


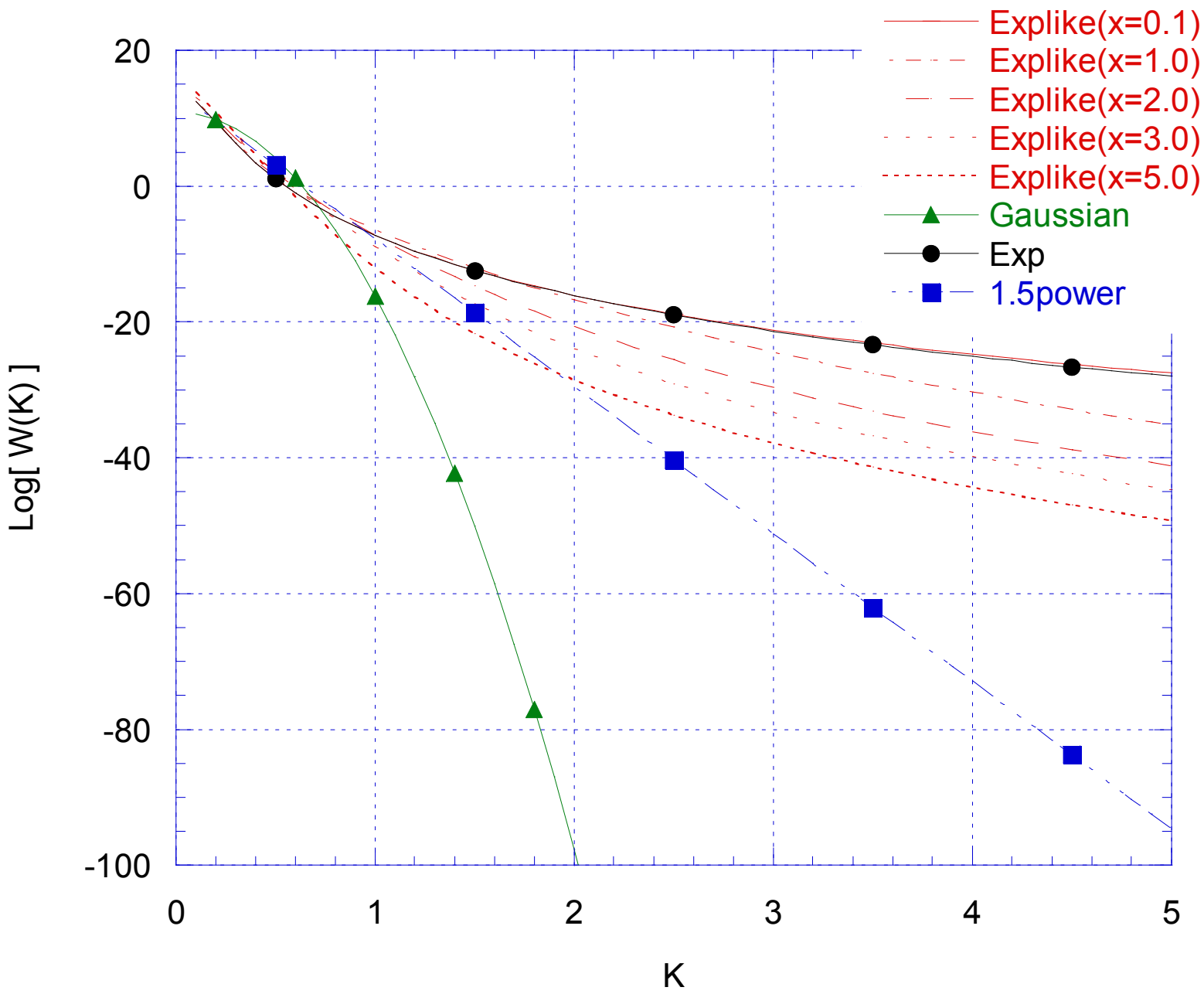
Exponential Correlation function :

$$C(x,y) = h^2 \exp\left(-\frac{\sqrt{x^2+y^2}}{l}\right)$$

$$W(k) = \frac{h^2 l^2}{2\pi[1+(kl)^2]^{\frac{3}{2}}}$$

rms height = 0.5
cl = 2.5




Explike(x=0.1)
Explike(x=1.0)
Explike(x=2.0)
Explike(x=3.0)
Explike(x=5.0)
Gaussian
Exp
1.5power
20
0
-20
-40
-60
-80
-100
0
1
2
3
4
5
Log[W(K)]
K

The relative permittivities of wet soil

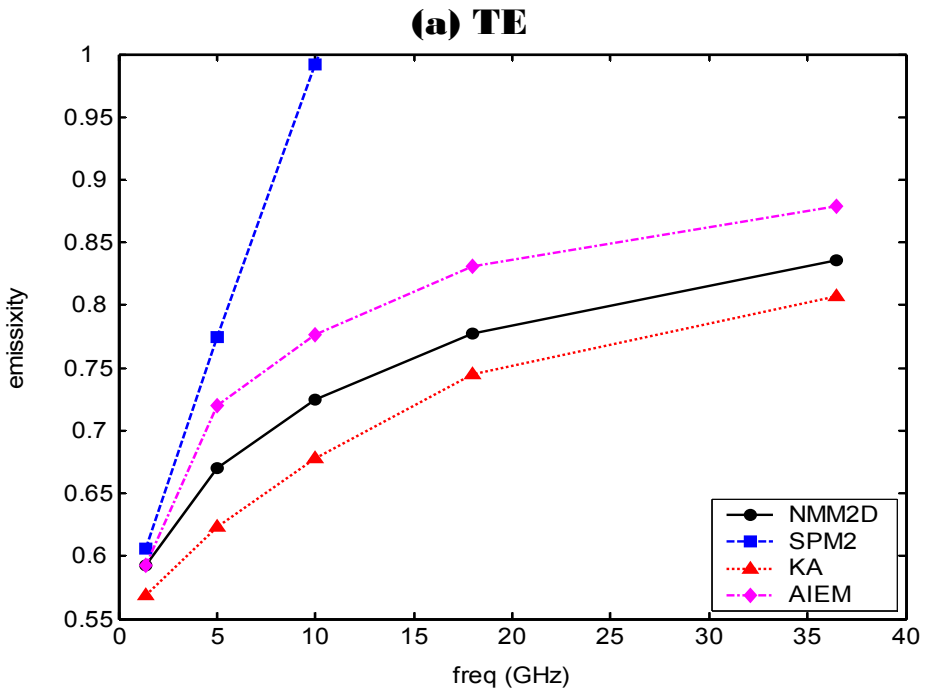
[M. T. Hallikainen etc, TGRS,1985]

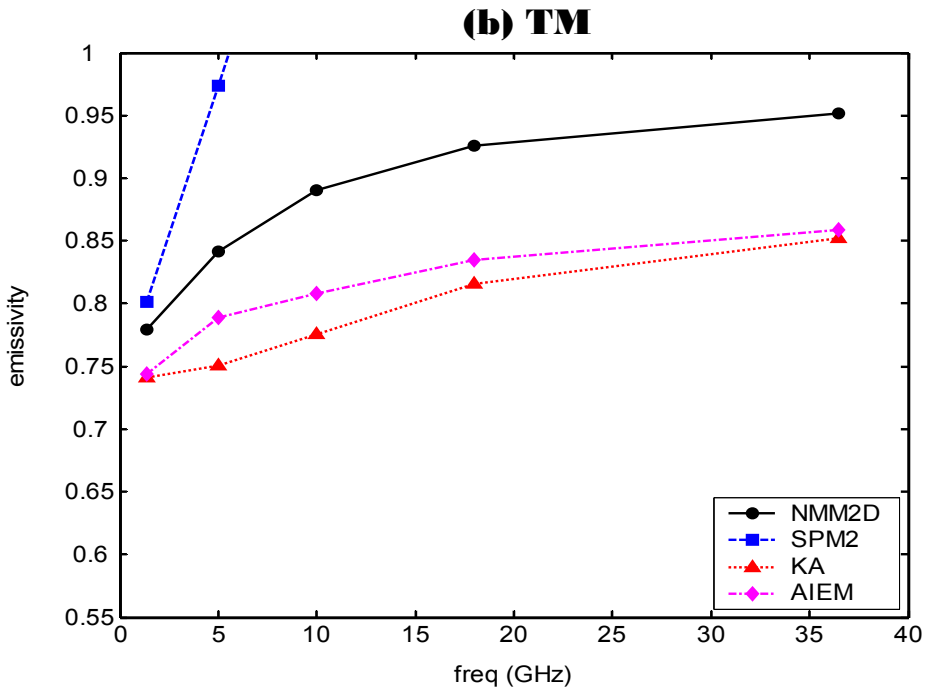
- The relative permittivities of wet soil for
- a silt loam with sand of 17.16%,
- silt of 63.84%,
- clay of 19.00%,
- volumetric moistures of 30.6%

Freq (GHz)		1.4	5	10	18	36.5
permittivity	Real	15.22	15.57	14.15	10.85	8*
	imag	3.45	3.71	5.21	6.13	7.5*

*estimated by interpolation

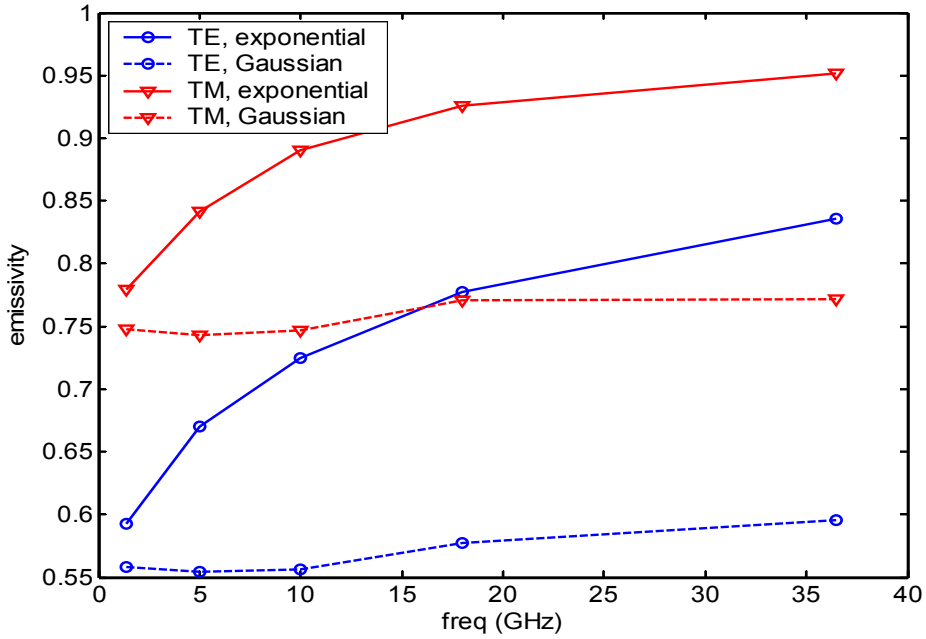
Emissivity: NMM2D with AIEM, KA, SPM2



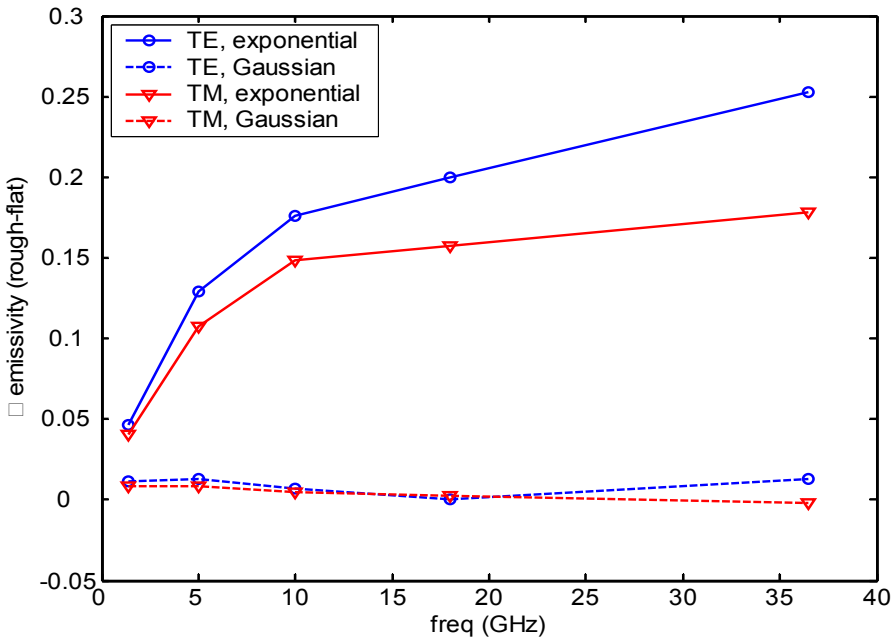


- Exponential correlation, θ= 40 deg., rms h = 1 cm, cL = 6 cm Sampling: 40/λ, length: 100λ
- average over 10 realizations
- SPM2 over-estimate for both polarizations
- KA under-estimate for both polarizations
- AIEM over-estimate for TE while under-estimate for TM

Comparison of emissivities between Gaussian and exponential correlated surfaces



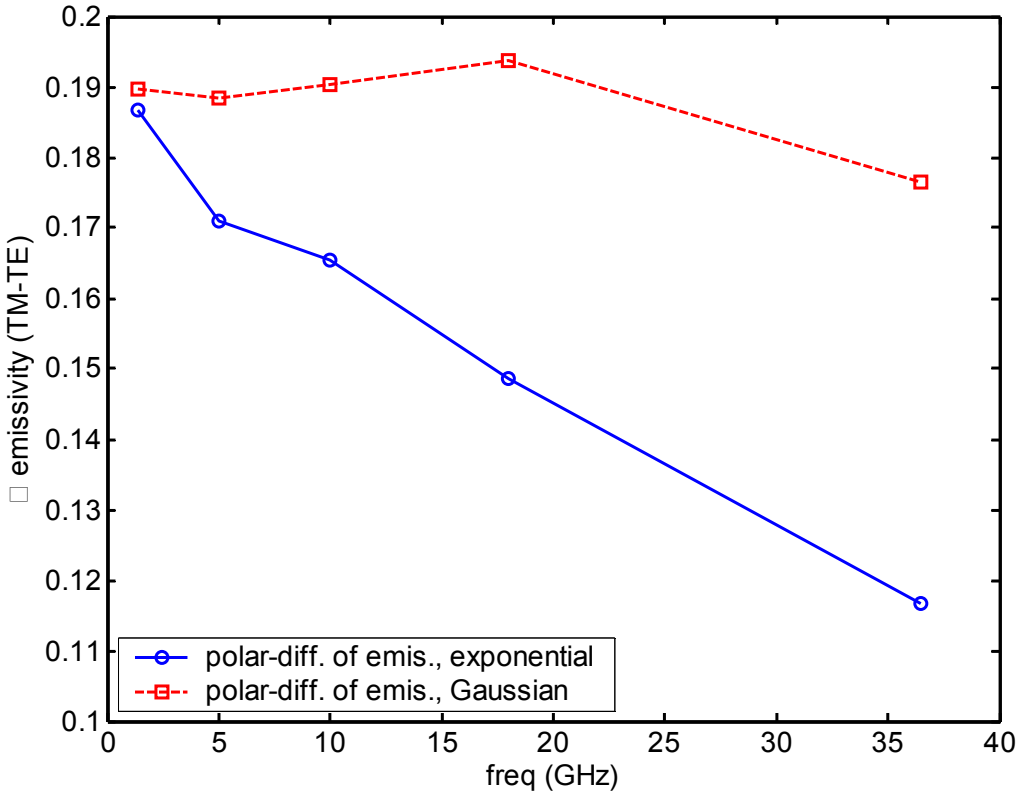
(a) emissivity



(b) Δemis. (rough-flat)

- θ= 40 deg., h=1cm, cL=6cm / averaged over 10 realizations
- emis. for exponential >> emis. for Gaussian
- emis. & Δemis. for exponential ↑with frequency↑ for both polar.
- Δemis. for Gaussian ~ 0

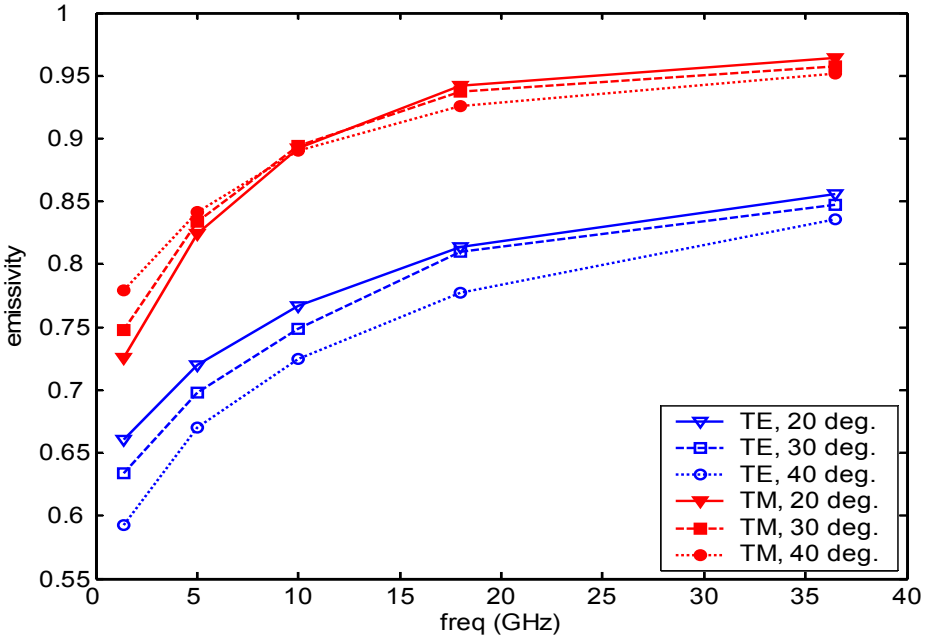
Comparison of emissivities between Gaussian and exponential correlated surfaces (con.)



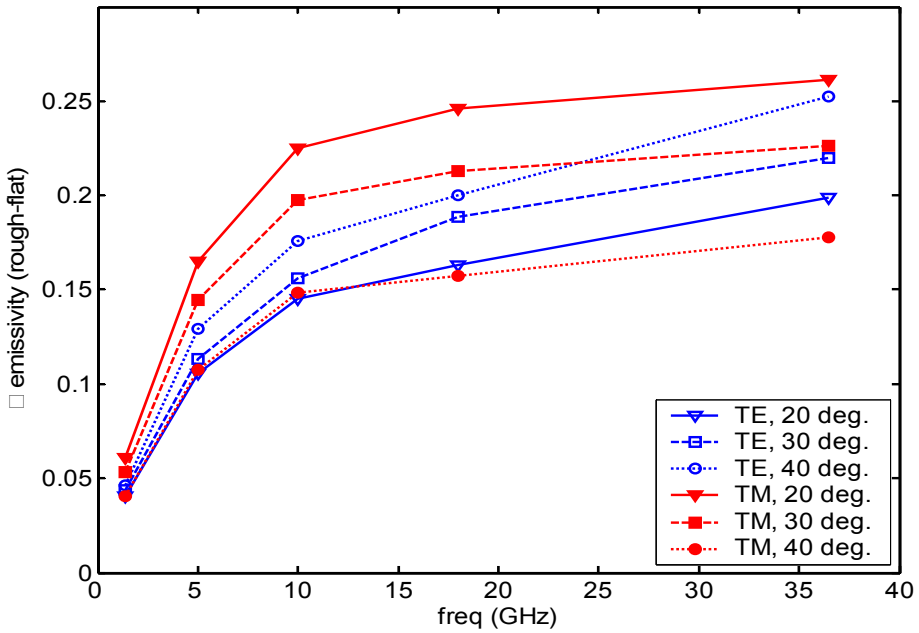
(c) Δemis. : TM − TE

- θ= 40 deg., h=1cm, cL=6cm
- Δ emis. More sensitive for exponential with frequency

Comparison of emissivity among different angles



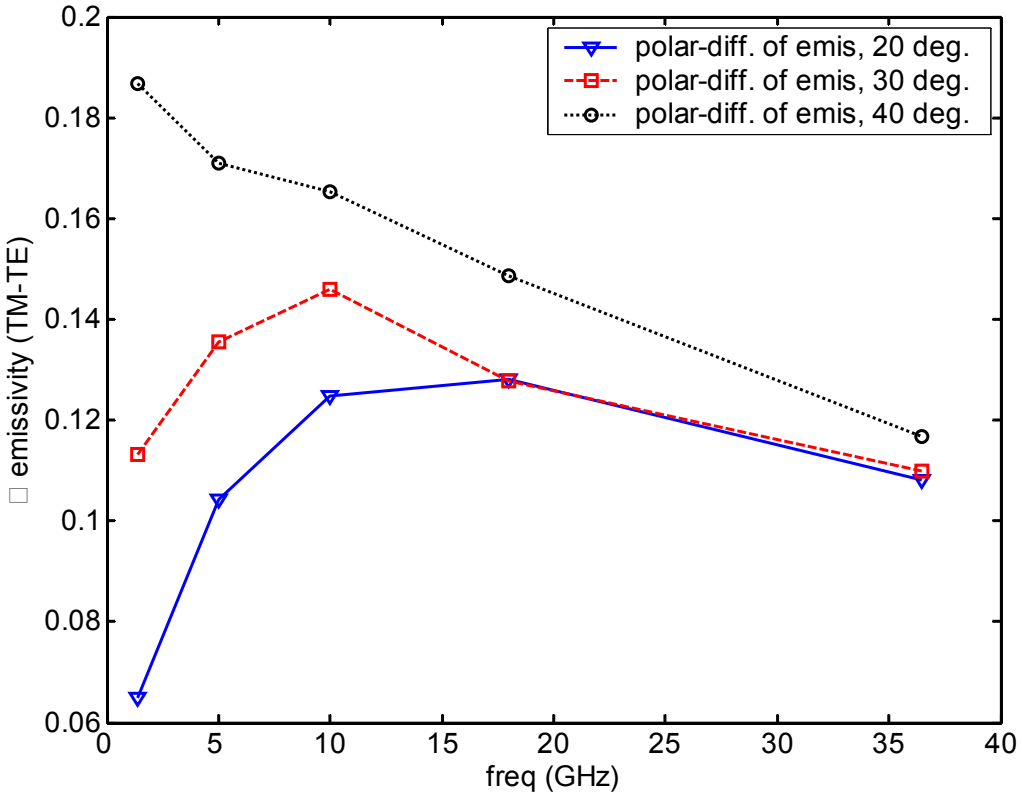
(a) emissivity



(b) Δemis. (rough-flat)

- Exponential, h=1cm, cL=6cm / averaged over 10 realizations
- emis. & Δemis. ↑ with frequency ↑
- Δemis. for TE ↑ with θ ↑
- Δemis. for TM↓ with θ ↑

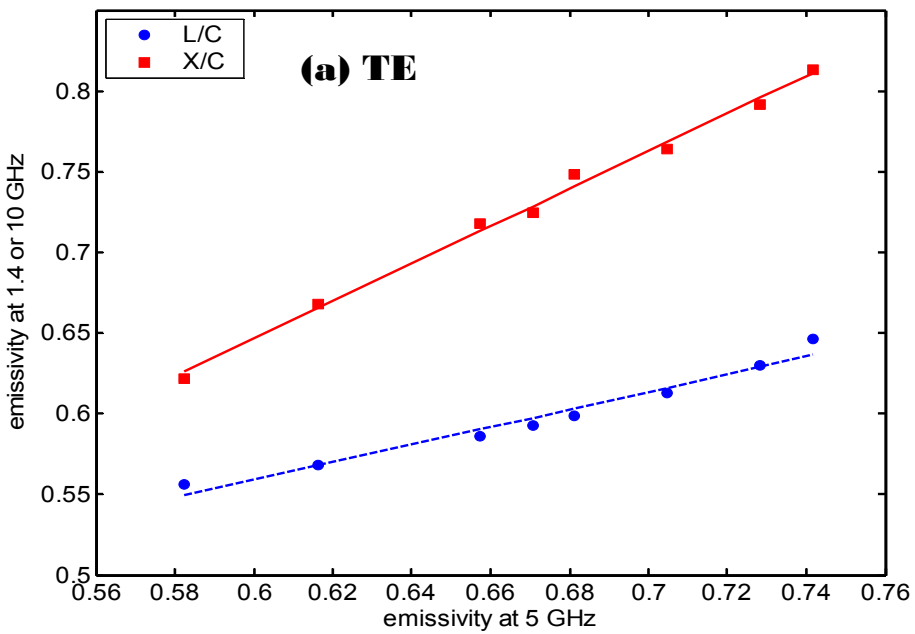
Comparison of emissivity among different angles (con.)

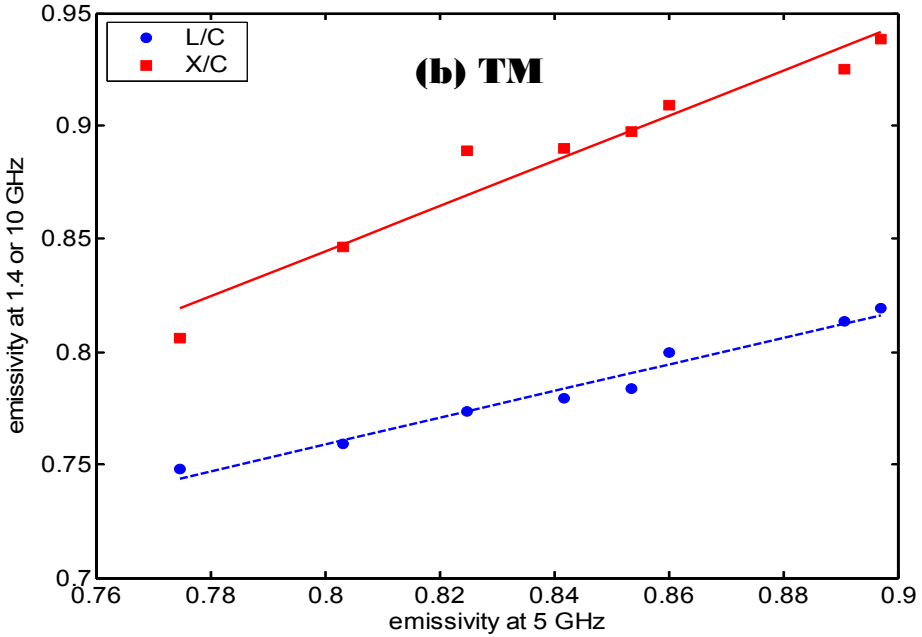


(c) for Δemis. : TM − TE

- at 40 deg, Δemis. ↓ with frequency ↑

Frequency correlation

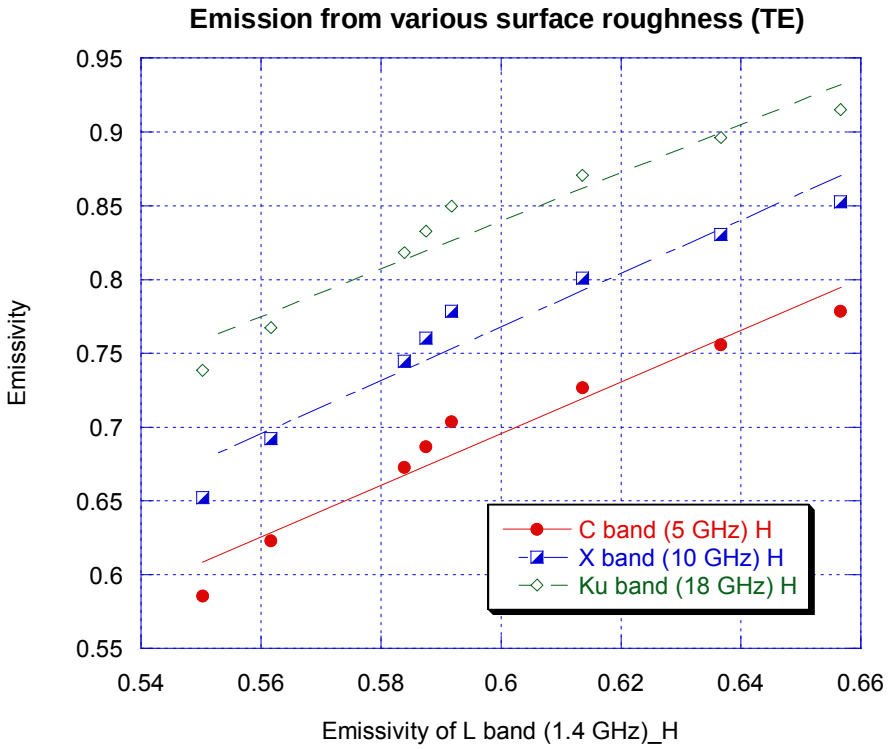


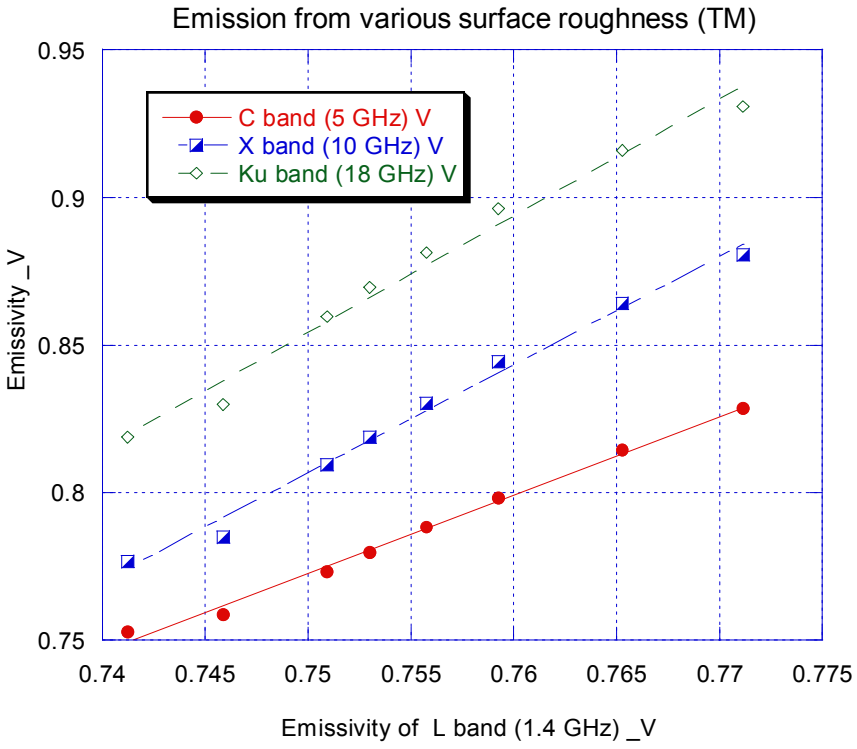


- Straight lines are least square fit
- exponential correlation

$$\begin{cases} h = & 0.25, & 0.5, & 1, & 1, & 1, & 1.5, & 2, & 2.5cm \\ l = & 1.5, & 3, & 7, & 6, & 5, & 9, & 12, & 15cm \end{cases}$$

Frequency correlation





Summary

- Numerical Maxwell Model Based on 2-Dimensional Numerical Solutions of Maxwell equations (NMM2D)
- SPM2 only work at lower frequency
- SPM2 overestimates emissivities while KA underestimates.
- AIEM (single scattering only) overestimates for TE while under-estimates for TM
- Emis. for exponential >> emis. for Gaussian
- emis-differeces for TE case increase with increase of angles, however, those for TM case decrease with increase of angle.
- Frequency correlations for exponential correlated surface at various frequency bands are quite linear