Long baseline multistatic observations of non isotropic soil surfaces: application to soil moisture retrieval

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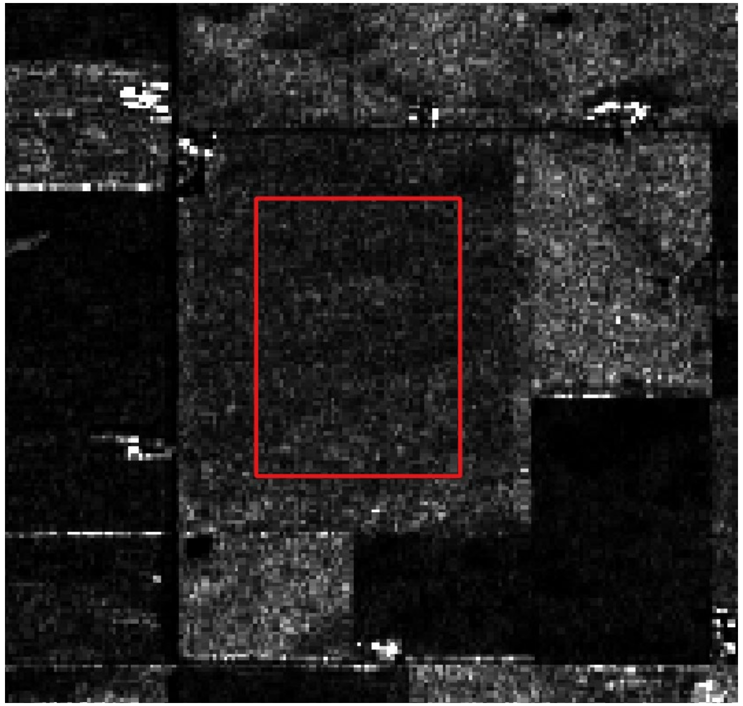
Outline

- State of the problem
- Methodology
- Results-Conclusions
- Work in Progress

“Flashing Fields”

- Airborne SAR acquisitions from two different viewing angles over the same area, considering the periodic pattern

09 July 2002, W-E, L-HH



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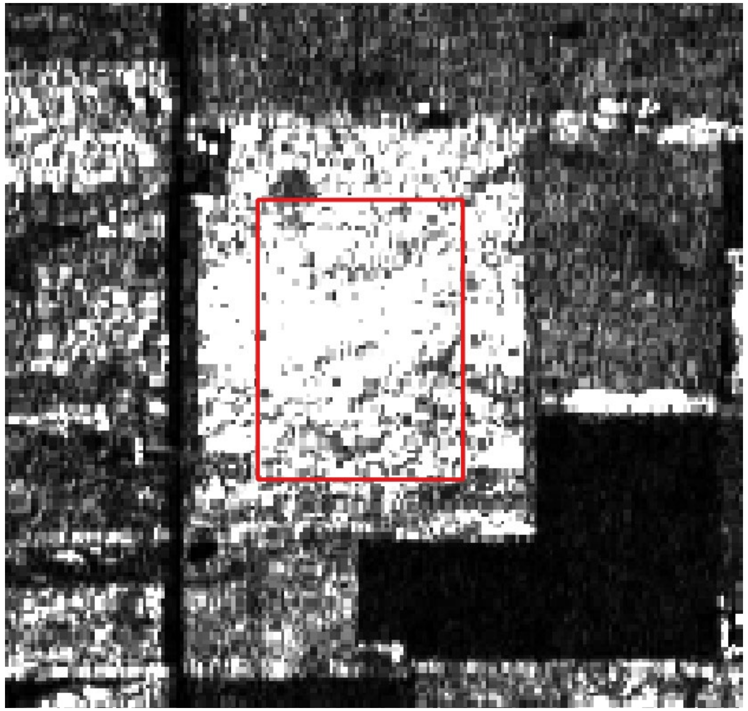
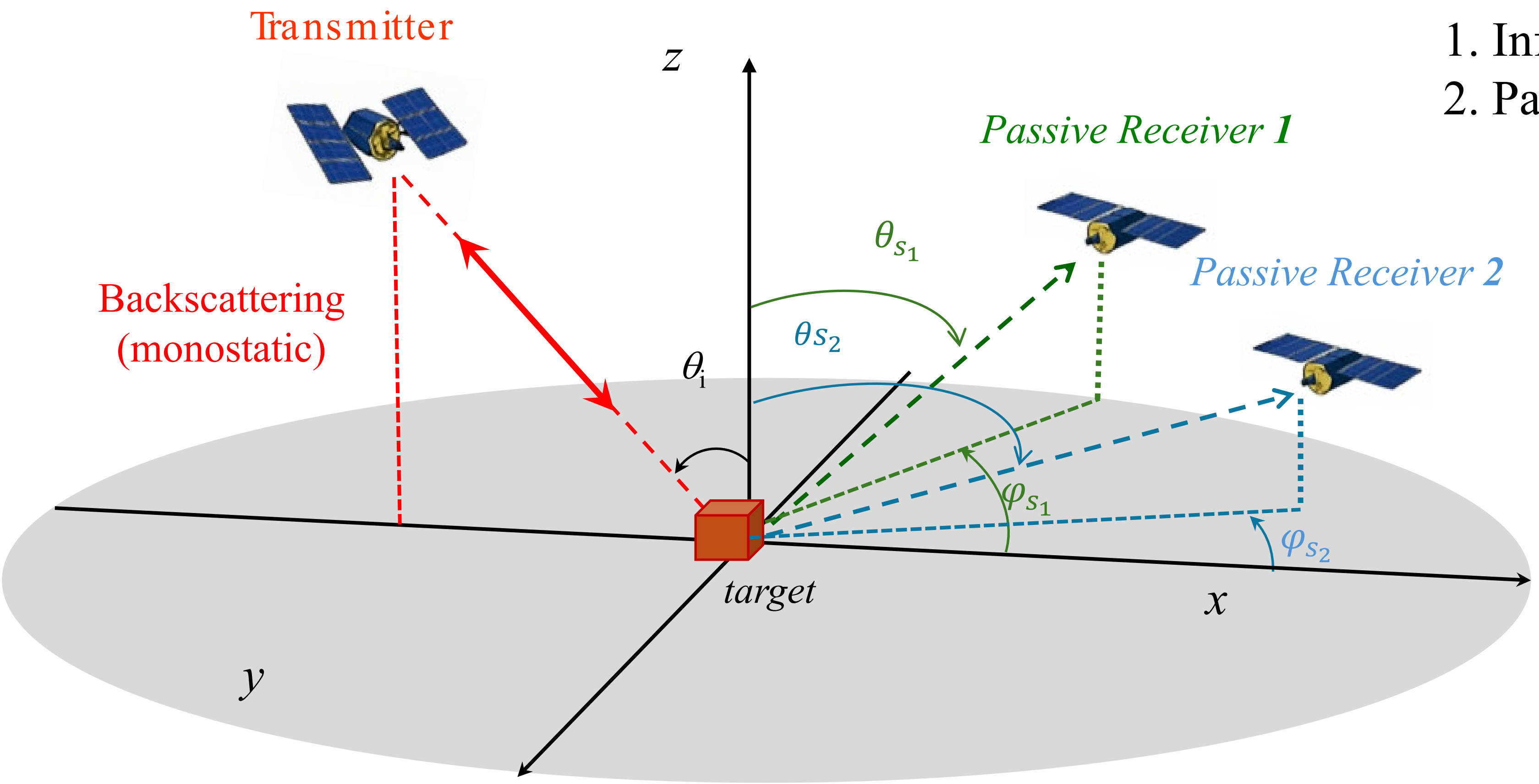


❖ Inability in estimating key **land surface parameters**

- Periodic Patterns can corrupt soil-moisture retrieval

U. Wegmuller, R. A. Cordey, C. Werner and P. J. Meadows, "“Flashing Fields” in Nearly Simultaneous ENVISAT and ERS-2 C-Band SAR Images," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 44, no. 4, pp. 801-805, April 2006, doi: 10.1109/TGRS.2005.861479

"Is a Multistatic Configuration a possible solution?"

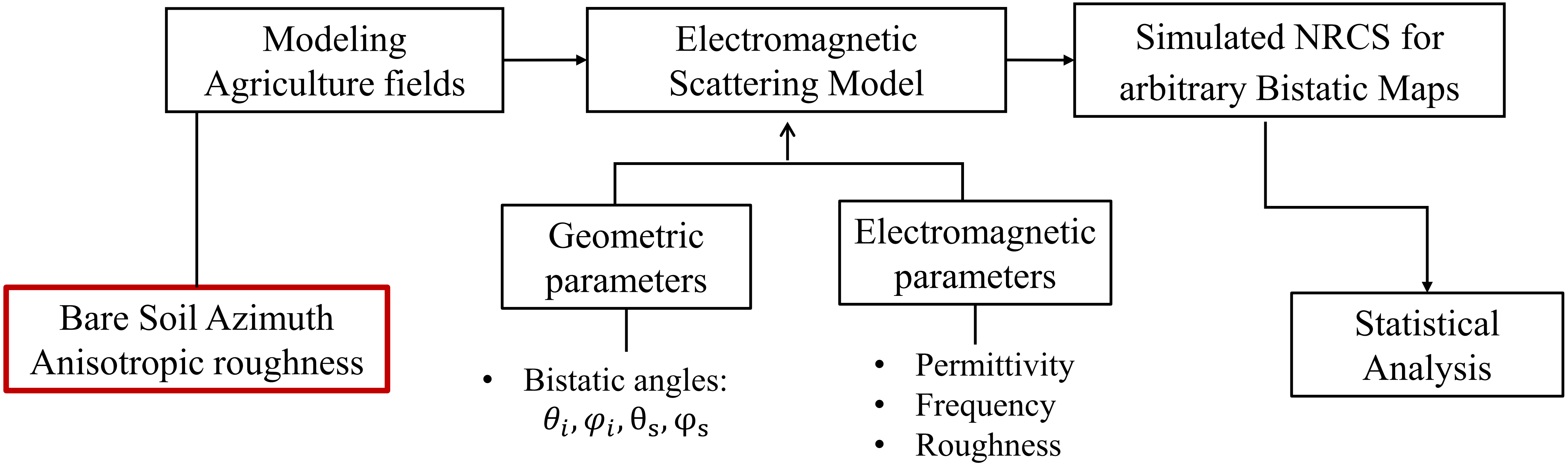


❖ **Why multistatic?**

1. Information diversity
2. Passive / opportunistic transmitters

Methodology

❖ **The study focuses on Parameters Error Estimation in Agricultural fields by utilizing Long Baselines Multistatic Radar Systems**



❖ Electromagnetic Modeling

Geometric parameters

EM parameters

Surface Characteristics

→ Electromagnetic Scattering Model → **Bistatic Normalized Radar Cross Section (NRCS)**

↓

Small Slope Approximation – First Order

$$SSA1(\bar{k},\bar{k}_0) = \frac{\sqrt{q_k\, q_0}}{2\pi^2 (q_k + q_0)}\beta(\bar{k},\bar{k}_0)\int e^{-i(\bar{k}-\bar{k}_0)\bar{r}}e^{-i(q_0-q_k)h(\bar{r})}d\bar{r}$$

β refers to a kernel function that depends on the material's permittivity.

$h(\bar{r})$ characterizes the surface roughness of the area under observation.

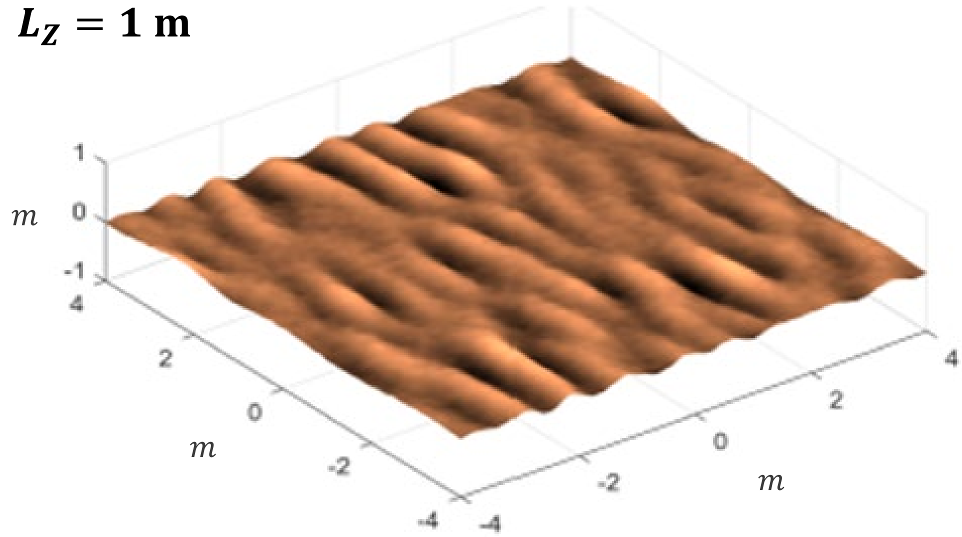
- A. G. Voronovich, "Small-slope approximation for electromagnetic wave scattering at a rough interface of two dielectric half-spaces," *Waves in Random Media*, 1994.
- M. S. Gilbert and J. T. Johnson, "A study of the higher-order small-slope approximation for scattering from a Gaussian rough surface," *Waves Random Media*, 2003.

❖ Anisotropic Surface: Approach based on a Double Scale Model

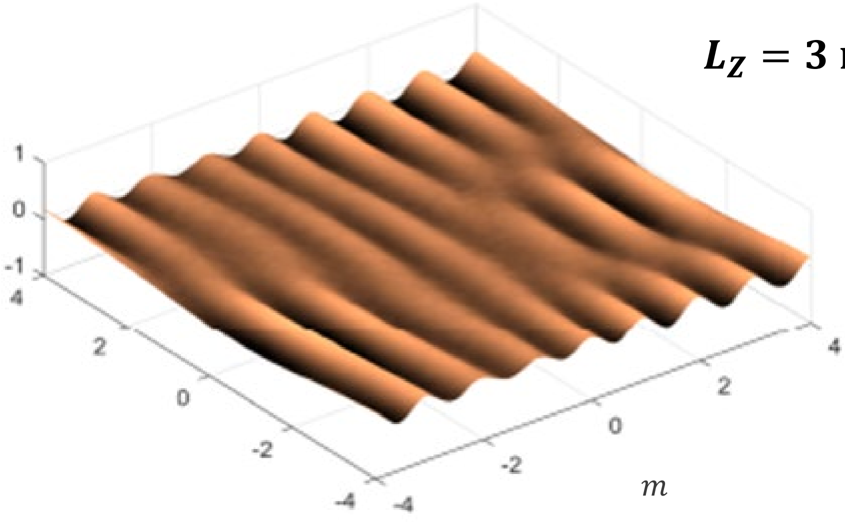
Random height profile: $\boldsymbol{z = \zeta(x,y) + Z(x,y)}$

Isotropic small scale ↲ (for $\zeta(x,y)$) ↳ Anisotropic large scale (for $Z(x,y)$)

$\boldsymbol{L_Z = 1}$ **m**



$\boldsymbol{L_Z = 3}$ **m**



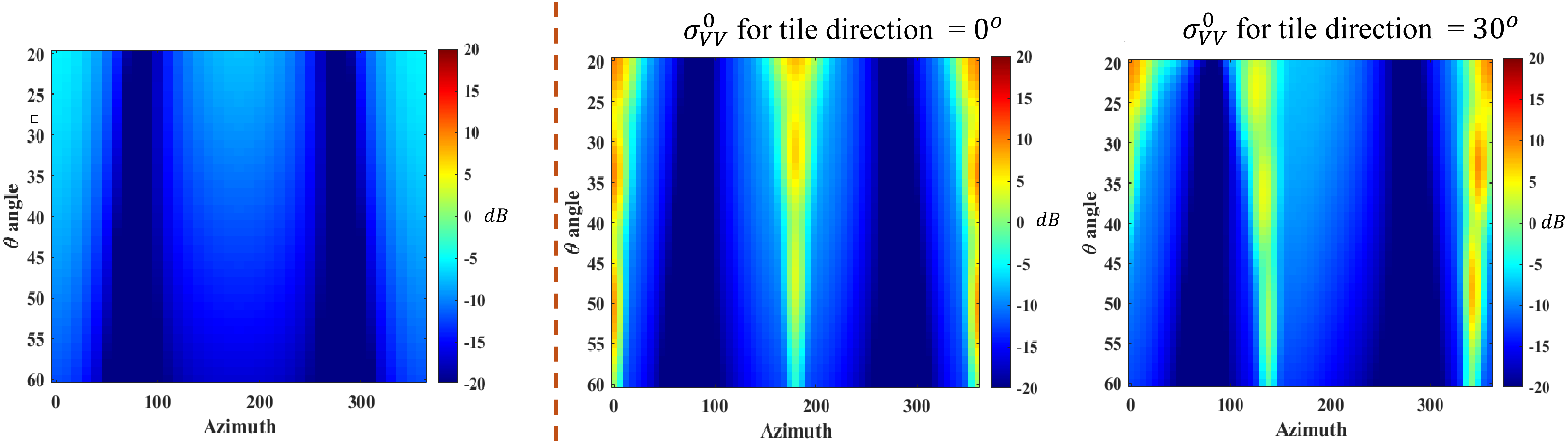
$\boldsymbol{L_Z}$ **↑ the surface gradually resembles to the unperturbed periodic surface**

Small Scale Corr.Length: $\boldsymbol{L_\varsigma = 0.1}$ **m,** Period of the quasiperiodic Surface: $\boldsymbol{P = 1}$**m,** Std of small-scale rough profile: $\boldsymbol{\sigma_\varsigma = 1}$ **cm,** Std of Large-scale rough profile: $\boldsymbol{\sigma_Z = 5}$ **cm** $\boldsymbol{L_Z}$: Large scale correlaiton length

D. Comite and N. Pierdicca, "Monostatic and Bistatic Scattering Modeling of the Anisotropic Rough Soil," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 57, no. 5, pp. 2543-2556, May 2019, doi: 10.1109/TGRS.2018.2874540

❖ **Bistatic Configuration $\theta - \varphi$ for Normalized Radar Cross Section representation**

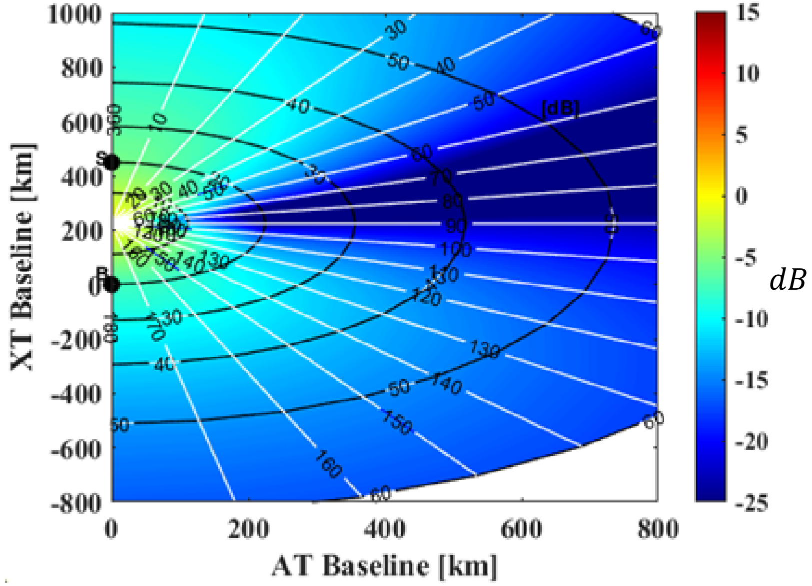
- **Isotropic Case**
- **Anisotropic Cases**



$L_\varsigma = 0.1$ m , $L_Z = 2$ m, $P = 1$ m, $\sigma_\varsigma = 1$ cm, $\sigma_Z = 5$ cm

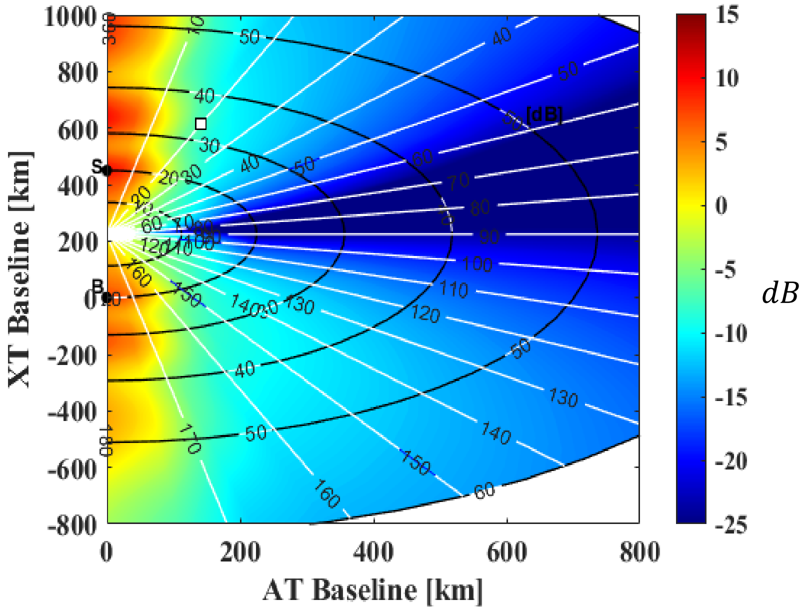
- **Bistatic Configuration with 2*D* Along Track (AT) - Cross Track (XT) maps for Normalized Radar Cross Section representation**

- **Isotropic Case**

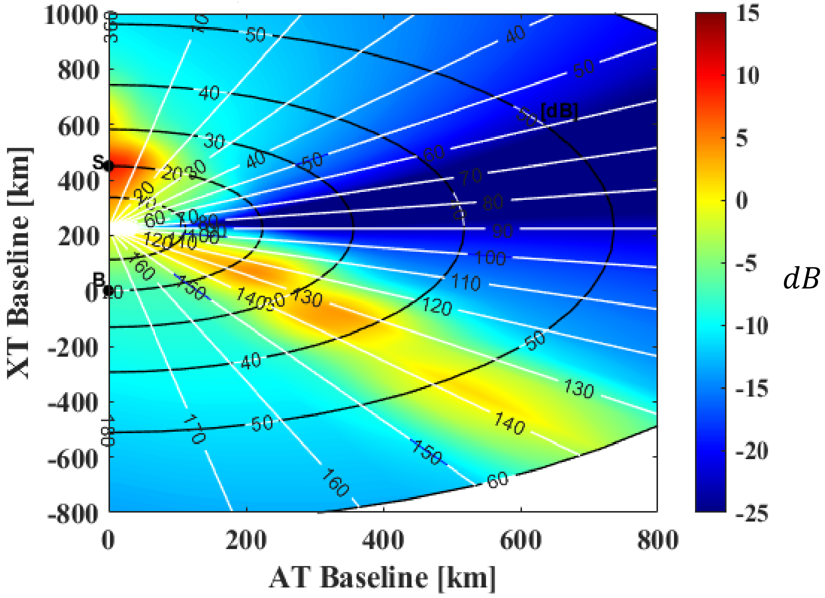


- **Anisotropic Cases**

σ_{VV}^{0} for tile direction $= 0^{o}$

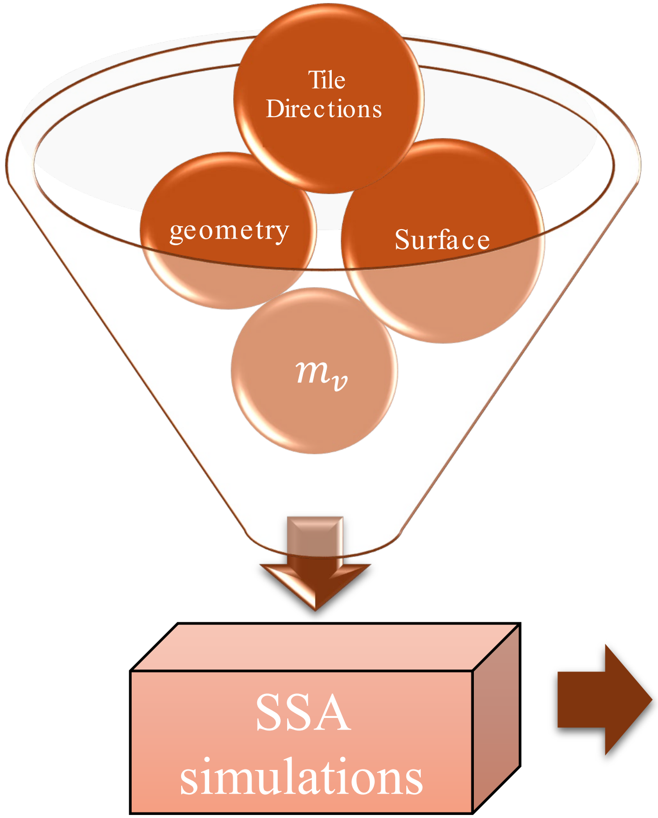


σ_{VV}^{0} for tile direction $= 30^{o}$



$L_{\varsigma} = 0.1$ m , $L_Z = 2$ m, $P = 1$ m, $\sigma_{\varsigma} = 1$ cm, $\sigma_Z = 5$ cm

Multiparametric Problem



•**Objective**:

Investigating the **potential of multistatic radar** (currently co-pol NRCS in L-Band) to:

Estimate **soil moisture**

Infer **periodic orientation (tile direction of agricultural field)**.

Cramer Rao Lower Bound

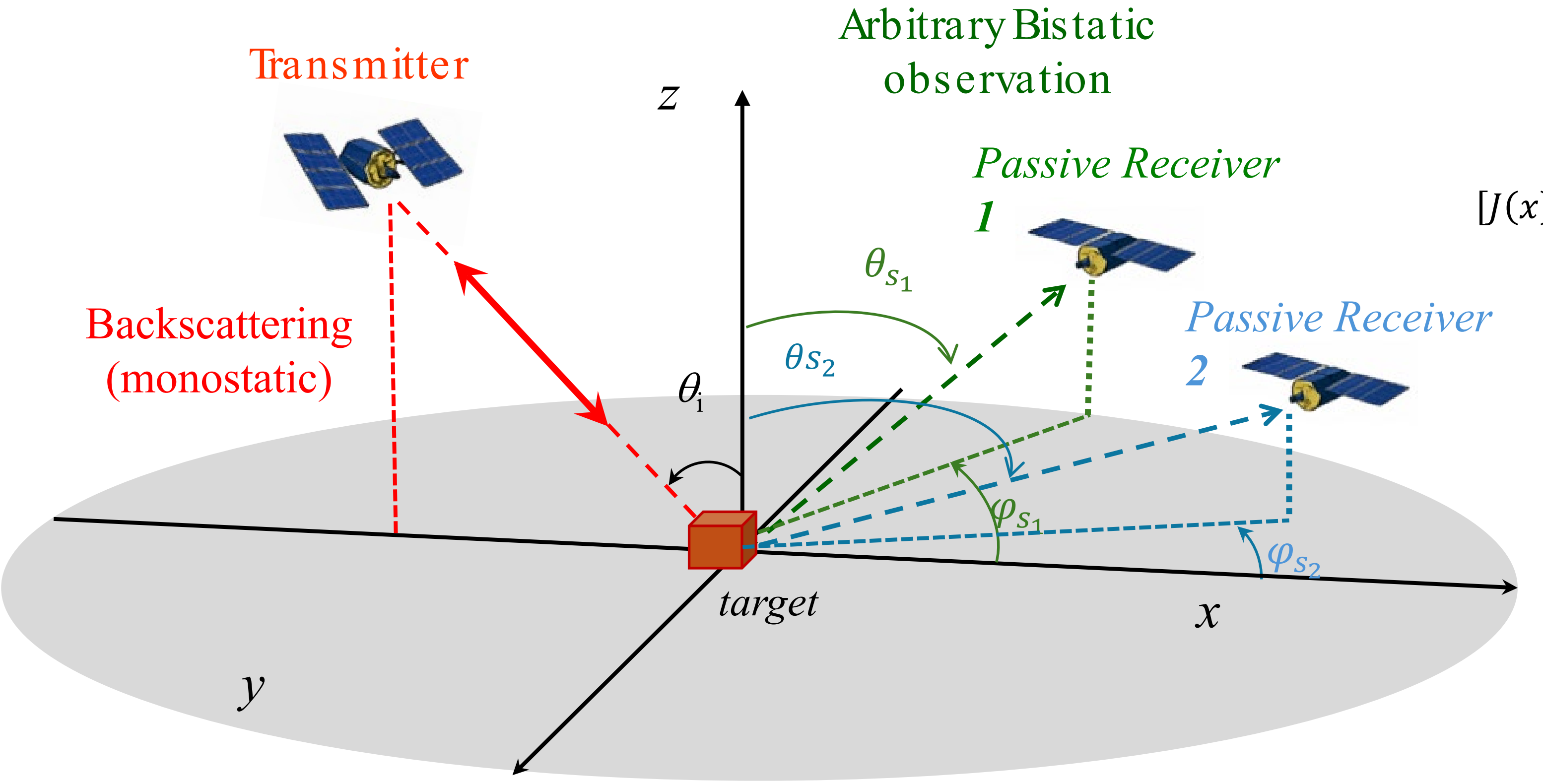
Evaluation of the limits of estimation accuracy as a function of bistatic geometry

First Approach

- Assuming all the parameters known in the simulations of NRCS except of the **tile direction** and the **permittivity → soil moisture**
- Roughness std parameter considered known

- **Cramer Row Lower Bound Estimated by means of sensitivity analysis of NRCS**

$$var(\hat{x}_i) \geq CRLB = \{[J(x)^{\mathrm{T}}\Sigma^{-1}J(x)]^{1}\}_{ii}$$

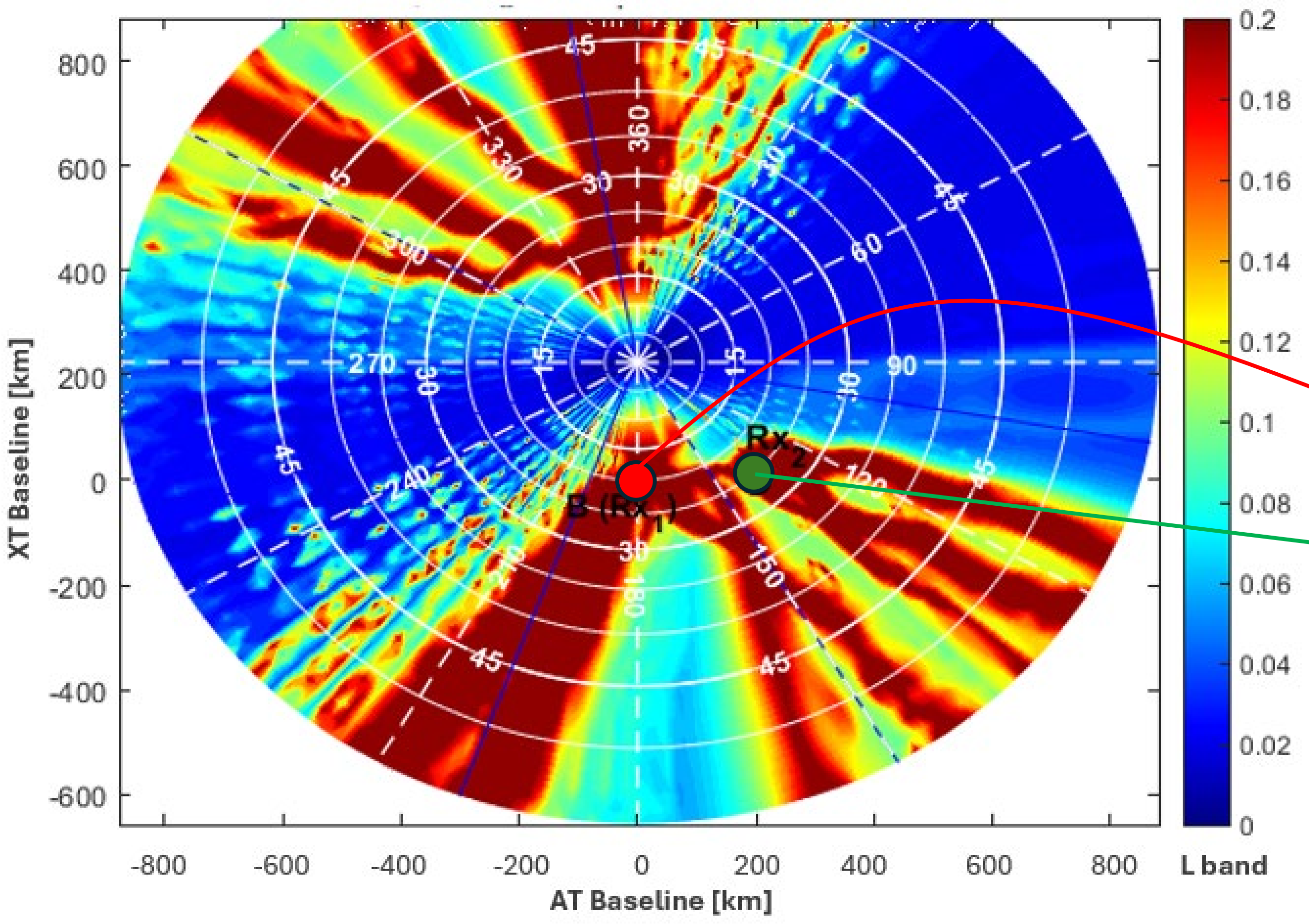


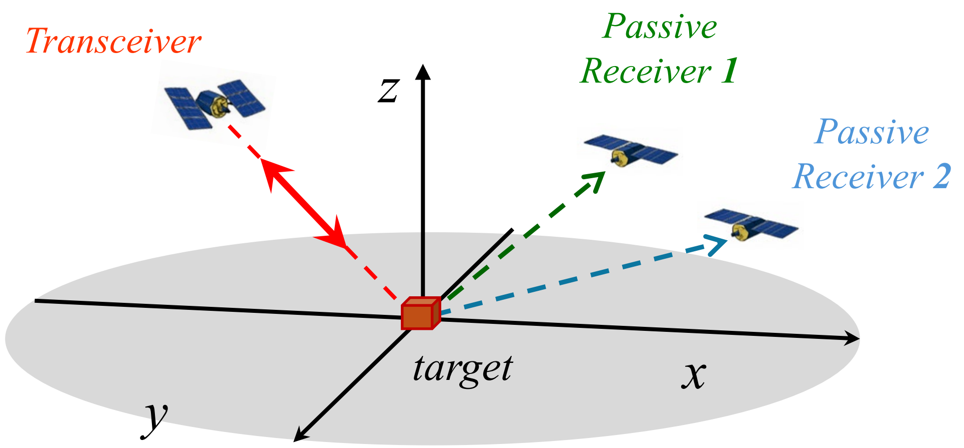
$$[J(x)] \approx \begin{bmatrix} \frac{\Delta\sigma_{VV}(backscatter)}{\Delta m_v} & \frac{\Delta\sigma_{VV}(backscatter)}{\Delta\varphi_{soil}} \\ \frac{\Delta\sigma_{VV}(passive1)}{\Delta m_v} & \frac{\Delta\sigma_{VV}(passive1)}{\Delta\varphi_{soil}} \\ \frac{\Delta\sigma_{vv}(passive2)}{\Delta m_v} & \frac{\Delta\sigma_{VV}(passive2)}{\Delta\varphi_{soil}} \end{bmatrix}$$

Results

❖ Error Estimation for **soil moisture**, evaluating different combination (different values of soil moisture & tile orientations)

Bistatic Plot of the **worst-case tile orientation scenario**



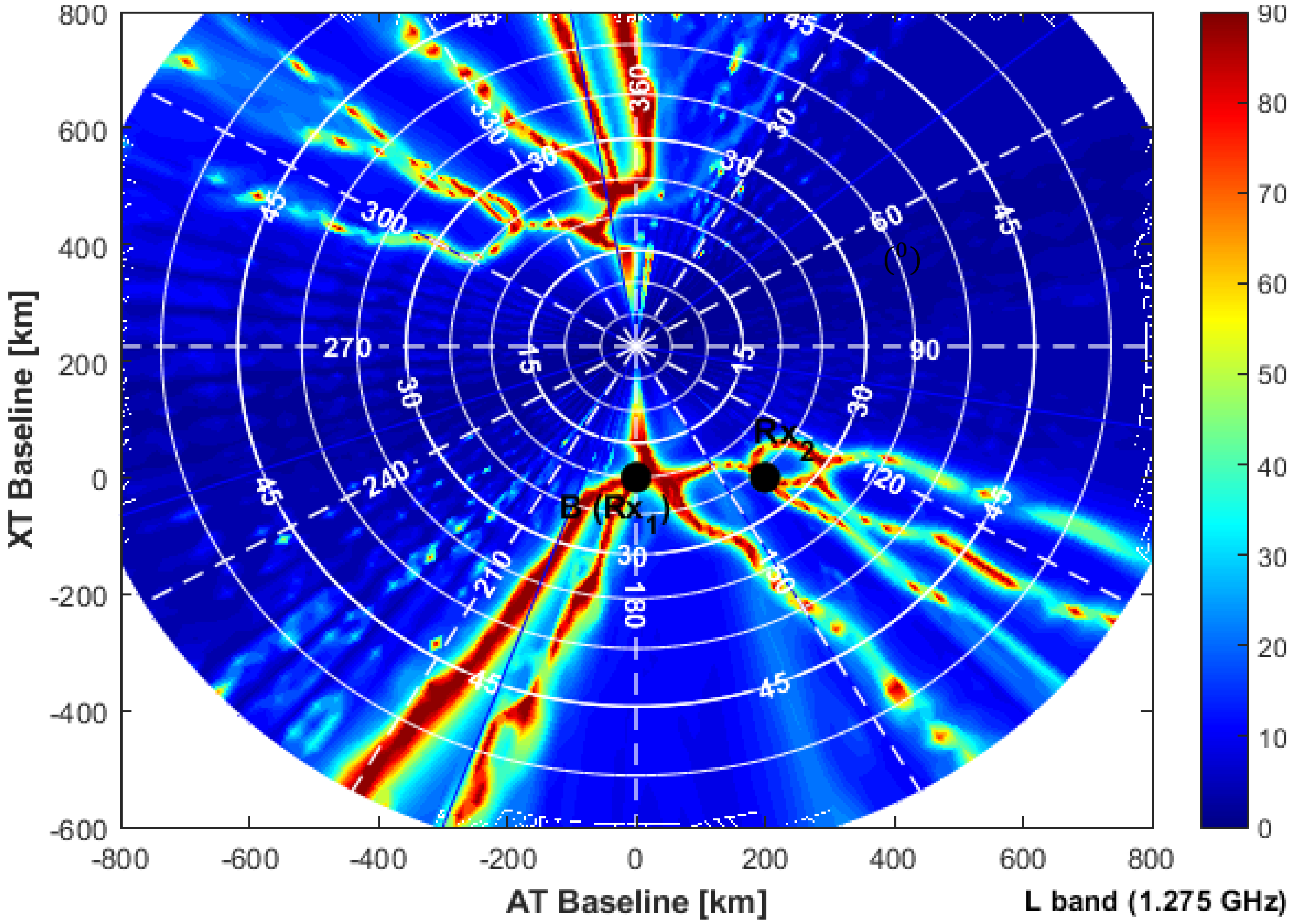


- Active transceiver B(Rx_1) positioned at the origin of the along-track (AT) and cross-track (XT) coordinate system
- *Passive Receiver* 1−Rx_2: is fixed and aligned along the track defined by the active system at a distance of 200 km
- Passive Receiver 2 placed symmetrically with respect to the first one with long AT baseline provide good estimation

❖ Error Estimation for **Tile Direction**, evaluating different combination (different values of soil moisture and & tile orientations)

From the full set of simulations, we present the estimation dynamics under **the worst-case tile orientation scenario** for each bistatic configuration (AT–XT)

- Second passive placed symmetrically with respect to the first one with a wider range of AT baseline provide good estimation



❖ Take-away messages

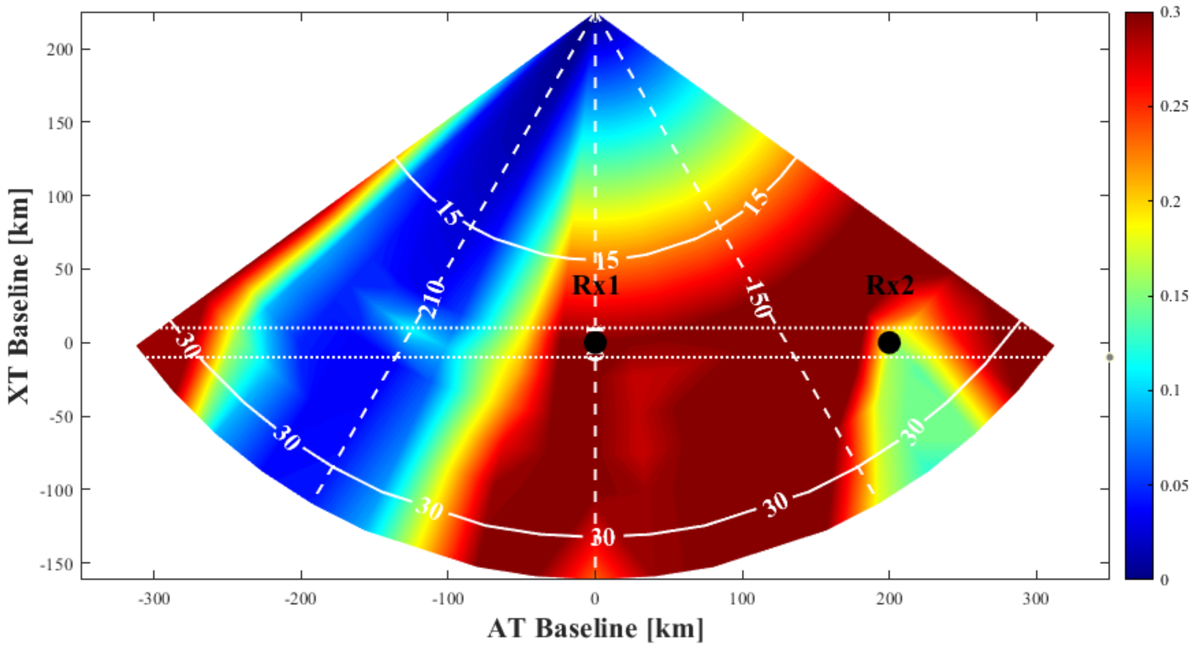
1. The Multistatic geometry offers a broader observation space
2. Well-promised to face the problem of "Flashing-Fields"
3. SSA combined with double-scale statistics reproduces them faithfully.

❖ Work in Progress

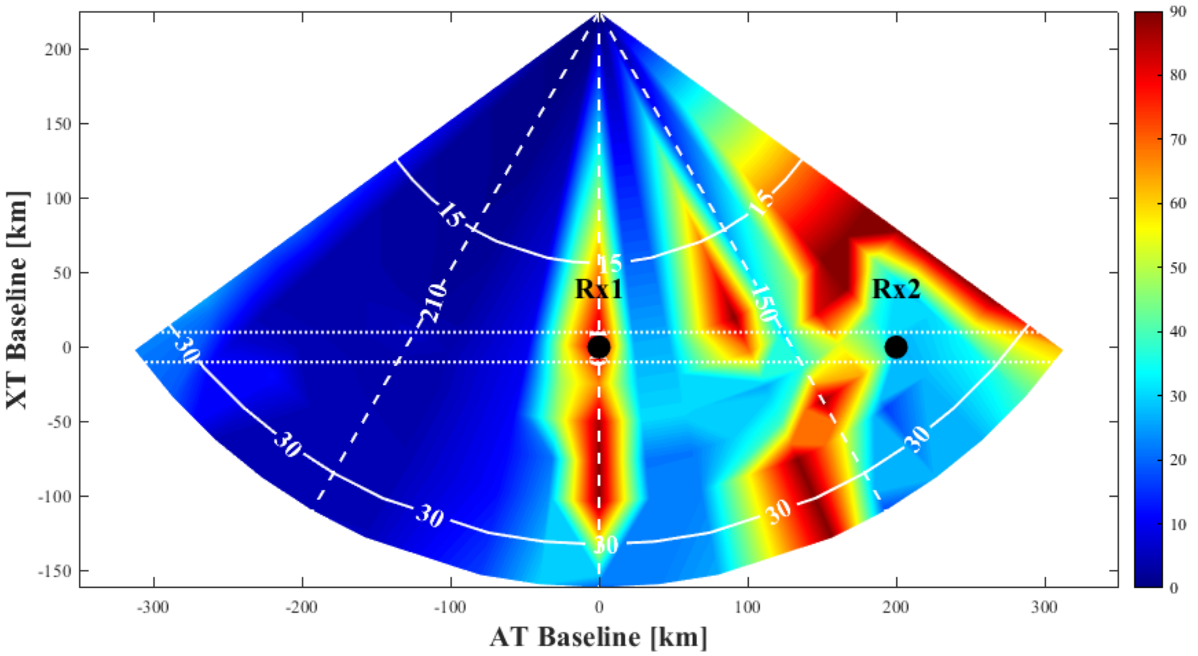
1. Expand the study into more variables.
2. Utilize the Second order Small Slope Approximation to evaluate the contribution of cross-polarization modes.
3. Investigate more frequencies

❖ Cramer Row Lower Bound Estimated by means of sensitivity analysis of NRCS

Error Estimation for **soil moisture**



Error Estimation for **tile direction**



Thank you !!!